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New Joint Sealants

Criteria, Design, and Materials

Publication No. 1006

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New Joint Sealants

Criteria, Design, and Materials

Publication No. 1006

Report of a program
held as part of the
BRI 1962 Spring Conferences

Building Research Institute

NEW JOINT SEALANTS

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Milton C. Coon Jr.
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Joint Criteria Based on Performance Experience

Sealing Concrete Joints

By T. W. Hunt, Portland Cement Association

Abstract: Sealants for concrete curtain wall panels are classified as cement mortars, oil-base calking compounds, and polysulfide sealants. Several case studies of success and failure of joint sealants are presented, showing that cement mortar is satisfactory for small concrete units, bricks, and stone masonry; that oil-base calking compounds are adequate for precast panels in the smaller units but need maintenance; and that polysulfide sealants are superior for sealing joints and between large concrete panels, with low maintenance.

SEALANTS FOR CONCRETE CURTAIN WALL PANELS may be placed in three general classifications:

1. Cement mortars
2. Oil-base calking compounds
3. Polysulfide sealants.

The first sealant ever used was probably a type of cement mortar developed during the Roman Empire period. With a number of refinements introduced during the intervening centuries, cement mortar is still used in great quantities for erecting buildings where relatively small units of wall materials are involved, such as concrete blocks, bricks, or quarried stone shapes. With such materials, the differential movement is not great; hence, mortar is usually an adequate sealant. Furthermore, the nature of the materials is such that movement takes place over a long period of time, resulting in a very gradual contraction or expansion.

Curtain wall panels are generally many times larger in surface area than concrete blocks or bricks, and their potential thermal movement may be greater than the holding capacity of mortar as a sealant. Consequently, cement mortar cannot be classed as a joint sealant for large concrete curtain wall panels. We could cite cases where mortar has successfully served for many years as a joint sealant for precast concrete panels of modest size, but for the larger panels used as curtain wall units, sealants other than mortar are used. These are the second and third types previously mentioned; i.e., oil-base compounds and polysulfide sealants.

HUNT, T. W. Decorative Concrete Specialist, Portland Cement Association; Fellow, American Society of Civil Engineers; member, American Concrete Institute.

Experience with these two general types of joint sealants, both favorable and unfavorable, will be discussed below.

About two years ago, the Portland Cement Association checked the performance of the joint sealants on some 50 buildings with concrete curtain wall panel exteriors in all sections of the country. This was accomplished by having our field engineers inspect the panel joints. They then obtained from the building superintendent information on the brand name of the joint sealant used, date of application, maintenance work performed, and other pertinent data, including panel size and manufacturer. All of this information for each building surveyed was recorded on separate data sheets previously prepared in outline form, to insure obtaining substantially the same type of information on each building. When all of the reports were assembled, we had a considerable amount of information as to the performance of joint sealants used with concrete panels.

CASE STUDIES OF PERFORMANCE

From this group of reports, a few case studies have been selected to illustrate both success and failure of the joint sealants. The first one concerns a five-story structure in Richmond, Virginia. This building has 4 x 12 ft. precast panels which have been in place since 1954. As the panel thickness was 5-1/2 in., a filler of dry jute (not tarred oakum) was packed in the joint, and the outer 3/4 in. was filled with an oleo-resinous calking compound of regular gun grade. The performance of the panel joints has been most satisfactory and, as of summer 1961, the calking material appeared to be in remarkably good condition.

The second case study concerns a 10-story apartment building in Des Moines, Iowa. Here, two sizes of panels were used: 3 x 24 ft., and 6 x 24 ft., with a thickness of 3 in. The panel joints were first filled with a mortar composed of 1 part masonry cement to 3 parts sand, then raked to a depth of 3/4 in., and later filled with a good calking compound. The sealant has performed well on this building, although it was necessary to perform some maintenance work on the joints after about four years. It is expected that occasional maintenance of the sealant will continue to be necessary.

The next case study is not a success story. A three-story office building in Atlanta, Georgia, had been inclosed with panels only 3 x 5 ft., and 3 in. thick (about the smallest panel size checked). The joints were sealed with an oil-base calking compound of gun grade. At the time of inspection, about 4 years after installation, the amount of sealant failure was classed as extensive, including breakdown of the calking material and loss of adhesion. The performance of the sealant was classified as bad.

A 19-floor office building in Denver, Colorado, had panels about the same size as those described for the preceding structure. The joint sealant, or calking, was of the same type, although a different brand had been used. This particular brand was performing satisfactorily at the end of six years, but an inspection made in March 1962 revealed that it may soon be necessary to remove and replace much of the calking. This compound has been used very successfully for many years by one of the leading producers of concrete panels. Recently, this firm has started to recommend polysulfide sealants, in order to reduce the amount of maintenance needed to insure continued weathertight joints between panels.

In a one-story office and warehouse building of large floor area in suburban Chicago, Illinois, precast concrete sandwich panels, 10 x 14 ft. with a thickness of 6 in., were used. Continuous neoprene shims were used as spacers in the joints, and the joints were then calked with an excellent grade of oil-base compound. Not long after the building was occupied, some minor leakage through the joints developed, which was traced to faulty calking. This was immediately corrected and, at the end of five years, the joint sealant was performing in a satisfactory manner. Indications were, however, that some maintenance work would be necessary before very long.

In contrast to the preceding structure, we checked a three-story office building in Cleveland, Ohio, where smaller panels had been used. The principal panel size was 4-1/2 x 6-1/2 ft. with a thickness of 5 in. The sealant used in the joints was the same excellent brand and formulation that had worked so successfully on the building just described above. However, on this project, the oil-base calking compound would not adhere to the concrete for more than a month. It was necessary to remove the calking material and replace it with a polysulfide joint sealant. Later, it was learned that the concrete panels had been treated with a waterproofing material before erection, and this may have been one reason the calking material lost adhesion in such a short time. Apparently, the waterproofing coating material had no effect on the adhesive properties of the polysulfide sealant, as it was in excellent condition at the end of five years.

In a three-story office building erected in Miami, Florida, panels 6 x 8 ft. were used for the exterior curtain walls. Several brands of oil-base calking compounds were used, possibly as an on-the-job test to learn which would give the best service. The test was not too successful, because one calking compound after another lost its elastic properties and became quite rigid. In a little over two years, it was necessary to replace all of the calking with a polysulfide joint sealant.

The next structure described might be termed an example of two failures followed by a success. It is an office building in the Miami, Florida, area, six stories high, with panels 5 x 10 ft. In construction, the panel joints were filled with a grout mortar which did not have much chance of succeeding because of the large size of the panels. In somewhat less than two years, there was evidence of water leakage through some of the joints, and a contract was made with a reliable firm to clean out the joints and recalk with conventional calking material. This second type of joint sealant lasted for a little less than four years, and then leakage began to develop again. It was necessary to remove all of the existing joint material, thoroughly clean the concrete joints, and seal them with a polysulfide joint sealant which to date has performed in a very satisfactory manner.

SUMMARY OF FINDINGS

In our check of various buildings, we found no case of failure where polysulfide sealants had been used and were properly installed. In the few rare cases where problems did develop, the trouble could be traced to faulty installation, and corrective measures were not too difficult.

To conclude, we can summarize our findings as follows: Cement mortar has been and still is a satisfactory joint sealant for small concrete units, bricks, and stone masonry. The relatively small size of these units does not fit the concept of curtain wall panels; hence, mortar performance has not been a part of our considerations. Before the development and widely accepted use of polysulfide sealants, various combinations of oleo-resinous calking compounds were used as sealants for precast panels of all sizes. With the smaller units, these joint fillers have in many cases been quite adequate, and occasionally they have worked well with large panels. However, in all installations using oil-base joint materials, maintenance at regular intervals is necessary to insure that the joints will continue to be weathertight.

The development of polysulfide materials for joint sealants has provided a means of sealing joints between large concrete panels in a manner superior to that achieved by other materials previously used. Failures have been extremely rare, and joint maintenance has been reduced to a very low point. Although the performance records of these sealants have been highly satisfactory, the various sealant manufacturers are continuing to strive for improvement in existing materials, and to develop new and better sealants. Some of the following papers will describe these new materials and developments. It may be too early to judge their performance, but it seems that the building industry can look forward to even better sealants in the near future.

Sealing Glass and Metal Joints

By James H. Valentine, Pittsburgh Plate Glass Company

Abstract: This paper discusses experience with three joint designs used in sealing glass and metal joints: the face glazing rabbet, the removable stop glazing rabbet, and the recessed or groove glazing rabbet. Face glazing is recommended only for panes less than 50 united inches where oil-base compounds are used, and conditions causing sealing failures are noted. The removable stop design permits easy installation and takes preference for large panes, but several cautions are observed. The recessed or groove design minimizes the joints to be sealed but presents serious glass setting and glazing problems. Six criteria for joint design are presented, with the conclusion that success is assured only by adherence to complete specifications.

SUCCESSFUL GLASS AND METAL JOINTS depend on three interrelated elements: good joint design, proper selection of sealing compounds, and good workmanship. The scope of this paper is to determine, from field experiences, the influence of joint design alone on success.

TYPES OF JOINT DESIGN

To this end, experience with three types of glazing joint design, which in principle present all the problems associated with wall joints, are discussed. These designs are the face glazing rabbet, the removable stop glazing rabbet, and the recessed or groove glazing rabbet.

The Face Glazing Rabbet

The oldest and most common rabbet design is the face glazing rabbet. It should be limited to the glazing of small lights of glass (less than 50 united inches) in homes and industrial buildings where oil-base compounds are customarily used. With an accepted and practically attainable glazing detail, as shown in Figure 1, no trouble has developed or should be expected. The cushioning

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VALENTINE, JAMES H. Technical Sales Representative, Adhesive Products Division, Pittsburgh Plate Glass Company; member, BRI.

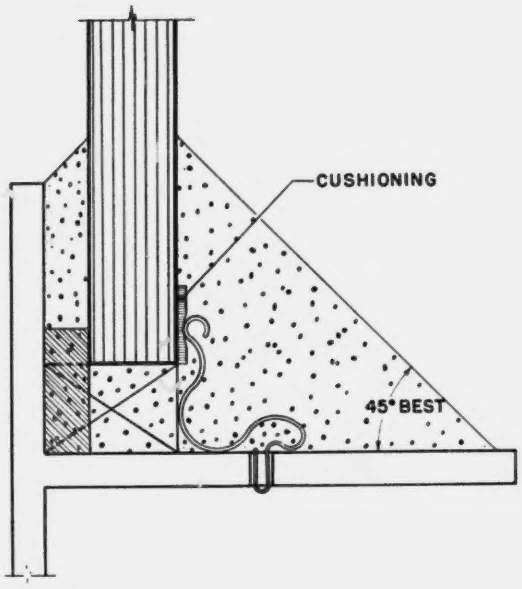

Figure 1 -- Face glazing rabbet design.

between the clips and glass is essential only when heat-absorbing glass is used. On the other hand, failures have occurred when:

1. Larger glass sizes were used.
2. Rabbet height, insufficient to provide at least 1/4 in. of compound seal over spacer shims, was detailed.
3. Shims have not been used to insure uniformly thick back bed.
4. Serrations, weld splatter, screw or rivet heads, or other irregular surface conditions, prevented cleaning the sash and void-free filling of the rabbet.
5. Relationship between the rabbet height and width caused a feather edge on the face glazing bead and led to drying and cracking of the "feathered" edge in 6 months. (Ideal is a 45° angle.)
6. Compounds were excessively "gassed" or thinned on the job for easier handling, especially in cold weather. Subsequent release of the volatiles causes shrinkage which creates water leakage paths.
7. Periodic maintenance and painting are not scheduled. Repairing localized areas of failure before they spread and painting to retard oxidation of the oils is the only way to get long-range performance with this system at reasonable expense.

Individually, these seven conditions are known to have caused seal failures with time. In one job, the first six produced a near catastrophe almost immediately. The details called for glazing 50 by 70 in. glass. This is more than twice the recommended maximum size for use with the specified oil-base elastic glazing compound. The rabbet depth was only 3/8 in. To add to the problem, there were rivet heads in the base of the rabbet. To provide a little clearance between the glass edge and the rivet heads, it was necessary to reduce the amount of glass edge buried in the rabbet to 3/16 in., which is much too little for effectively sealing this large glass under wind load. Within several months after completion, this job had to be completely reglazed because these windows leaked torrents of water. The job should never have been specified for face glazing because of the large glass.

The Removable Stop Glazing Rabbet

The removable stop glazing rabbet is the joint design that takes over when face glazing limitations are exceeded. In fact, the limit of glass size that can be used with this rabbet is the limit imposed either by the glass manufacturer's production capabilities, the strength of glass under wind loading, or the strength of the sash.

Regardless of the specific design for the removable stop type of sash, there are several points that have proven to be trouble spots. The most common of these is inadequate stop height. At the right in Figure 2 are shown the components that comprise stop height and minimum values for each. The glazing seal depth above the shims of a minimum 1/4 in. is a recommendation of the compound manufacturer to insure the performance of the glazing seals.

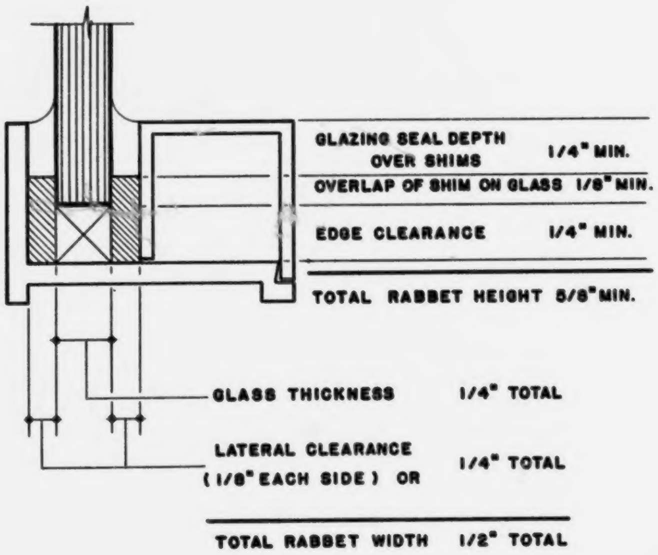
GLAZING SEAL DEPTH OVER SHIMS 1/4" MIN.
OVERLAP OF SHIM ON GLASS 1/8" MIN.
EDGE CLEARANCE 1/4" MIN.
TOTAL RABBET HEIGHT 5/8" MIN.
GLASS THICKNESS 1/4" TOTAL
LATERAL CLEARANCE (1/8" EACH SIDE) OR 1/4" TOTAL
TOTAL RABBET WIDTH 1/2" TOTAL

Figure 2--Removable stop glazing rabbet design, showing components comprising stop height and minimum values for each.

The 1/8 in. minimum overlap of shim to glass is to insure that the shims will actually serve the intended purpose of centering the glass in the rabbet. The edge clearance between glass and frame can vary from 1/8 in. minimum for glass size under 5 sq. ft. to 1/4 in. minimum or the thickness of the glass, whichever is greater, for glass over 5 sq. ft.

On this basis, the total then for a 4 ft. by 6 ft. by 1/4 in. light would be 5/8 in. minimum. Considering bow and warp tolerances in the frame, it is not at all generous to make stop height 3/4 to 7/8 in. The minimum width of the rabbet should be 1/4 in. plus the glass thickness.

Screws, rivets, and other such projections used in the attachment of hardware effectively reduce sash opening size and have been the cause of glass breakage. Almost 50% of the double-glazed units in one installation experienced breakage because the frames bowed and the glass edges of the units were supported on frame bolts instead of on the setting blocks as intended. Where these projections are used in the rabbets, stop height must be increased over the minimum to the extent of the thickness of these protrusions.

The fixed and removable stop glazing surfaces must be flat. As shown in Figure 3, nibs at the sight line reduce the compound cross section and, in many instances, make the glazing seals in these critical areas ineffective soon after installation. They also make cleaning of the stops and void-free filling of the lateral clearance voids most difficult. The effective stop height should be measured from the bottom surface of the nibs if they must be used.

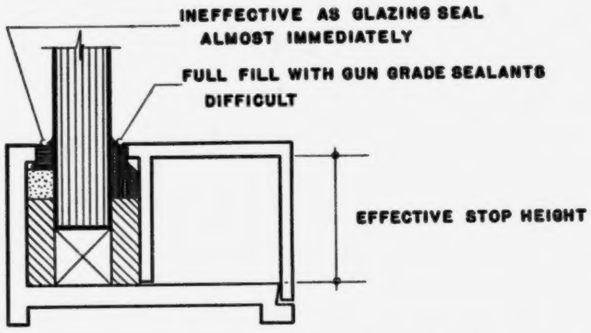
INEFFECTIVE AS GLAZING SEAL ALMOST IMMEDIATELY
FULL FILL WITH GUN GRADE SEALANTS DIFFICULT
EFFECTIVE STOP HEIGHT

Figure 3 -- Fixed and removable stop glazing surfaces must be flat. Nibs at sight line reduce the cross-section of the compound and render glazing seals in these critical areas ineffective soon after installation.

Figure 4 summarizes several points that, when omitted from sash or glazing details, lead to failures. Fixed stop corner joints should be made watertight by the manufacturer during sash fabrication. Every effort should be made to seal the metal joints around the removable stops, especially if these stops are to the indoors.

A weep system to the outdoors should be incorporated since it is practical to assume that some minor amounts of water may gain entry into the rabbet over the years.

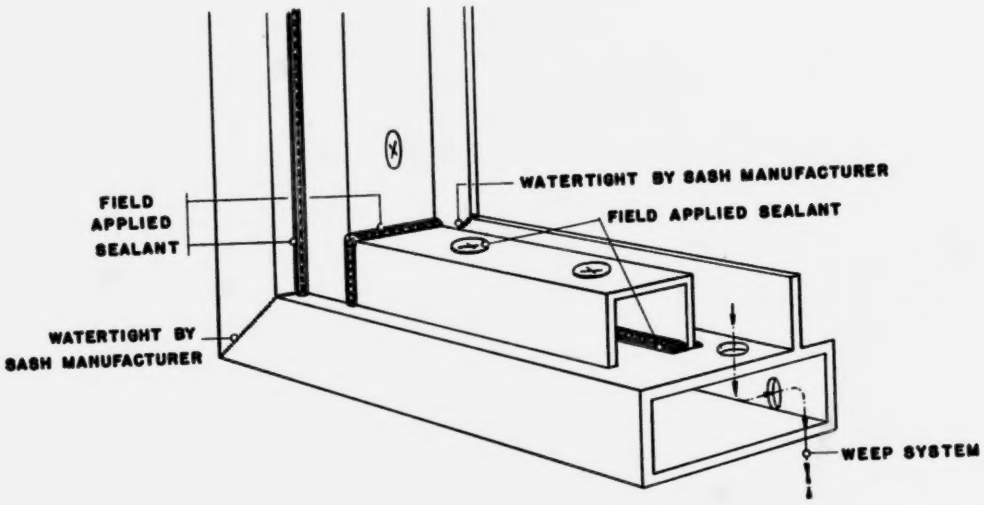
FIELD APPLIED SEALANT
WATERTIGHT BY SASH MANUFACTURER
WATERTIGHT BY SASH MANUFACTURER
FIELD APPLIED SEALANT
WEEP SYSTEM

Figure 4 -- Details that will prevent failures.

Now let us consider some particular removable stop designs. Figure 5 shows screw set stops (screws perpendicular) which serve two adjacent lights of glass. This is a very good design for fixed sash installations. The sealing surfaces can be readily cleaned, the glass easily installed, and with screws perpendicular to the glass edge, any type of glazing sealant can be considered. Since the stops generally cover the edges of two adjacent glass lights, only glazing joint and corner joint sealing is required.

Figure 6 shows screw set stops (screws at a 45° angle). This rabbet design has all the advantages of the previous type except for the additional seal required at the base of the stop. The most common problem with this and the previous design has been that the screws were not sufficiently long, or were easily broken or stripped.

Figure 7a shows a snap-on stop, outside pivot. This sash is ideal for easy glass setting and accessibility for cleaning. However, the stop design requires exacting dimensional control of the inside stop leg and engaging groove, to permanently lock the stop in place. With this control, it is readily set by tapping or using a clamping tool. During the setting of the stops, a glazing sealer can be compressed to better the flow and seal to the glass and sash surfaces.

Figure 7b shows a snap-on, inside pivot-type stop. This is essentially the same as the previous design except that the setting of this stop can be difficult since glass centering shims have to be compressed. As shown at the right in Figure 7b, when non-vulcanized sealants have been used, this initial "over-compression" produces internal voids or sealant let-go requiring tooling of the indoor and outdoor seals. When the need for tooling is not recognized, water leakage paths exist immediately.

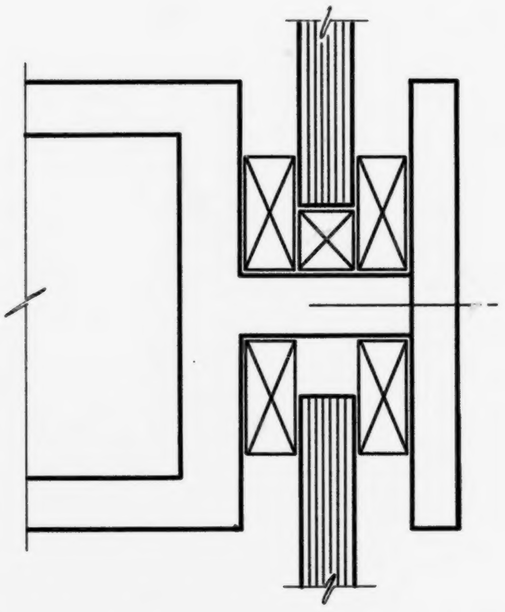

Figure 5 -- Screw-set stops, with screws perpendicular, to serve adjacent lights of glass.

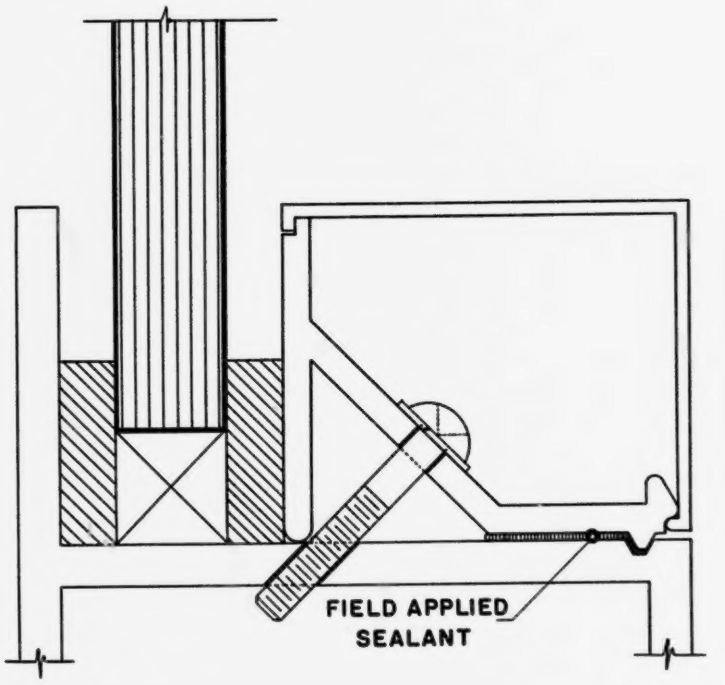

Figure 6 -- Screw-set stops with screws at 45° angle.

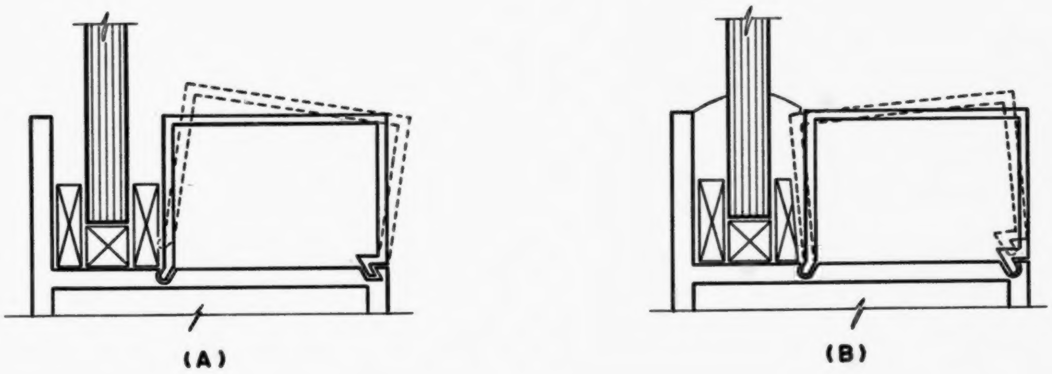

Figure 7 -- (A) Snap-on stop, outside pivot. (B) Snap-on stop, inside pivot.

On more than one building, snap-ons of both types could not be engaged properly because of the poor design of their locking mechanisms. Holes had to be drilled and self-tapping screws applied on the job to hold the stops in place. This defeated the intended purpose of neat appearance without screws and added to the installation costs.

Figure 8 shows screw set stops (screws parallel to glass). This figure has been detailed with removable stops, both sides, because this is the harder to seal. One advantage of this design is that it permits glazing from either side, depending on job conditions. But the big disadvantage has been that sealing one of the sides in the field cannot be done as effectively as a fixed stop can be fabricated and sealed in the factory. While this design permits easy glass installation, only limited compression can be obtained in setting the stops, unless auxiliary clamps or levers are used. Generally, only flow-in-space glazing sealants have been successfully used. The clearance holes in these stops are normally oversized, causing significant variation in sash rabbet width. Because of the lack of knuckle-room, the setting of the screws is also usually very difficult, requiring the use of offset screw drivers, which slows down production.

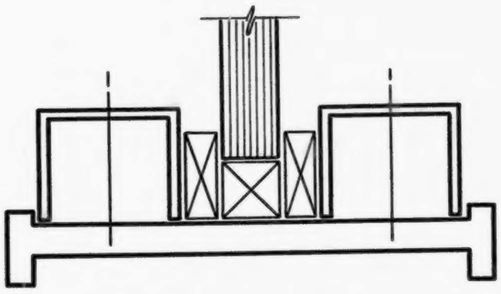

Figure 8 -- Screw-set stops with screws parallel to glass.

The Recessed or Groove Glazing Rabbet

Figure 9 shows the third basic rabbet design, the recessed or groove glazing rabbet. While this sash rabbet design is economical to manufacture and does minimize the number of joints to be sealed, it has presented the maximum of glass setting and glazing problems. The rabbet depth dimension must be twice the final glass edge encasement plus required glass edge clearances. In addition, the glass and sash size tolerances must be considered. The rabbet width dimension must provide ample room to swing the glass into the plane of the sash during its setting. Even with these considerations of sash rabbet dimensions, it may be difficult to control large glass setting without incurring glass edge damage. The glazing surfaces of this sash design are not generally accessible for easy cleaning. Unless the sash rabbet is extremely wide (3/4 in. or wider), a slow, generally ineffective, cleaning procedure must be used. This inaccessibility also limits or eliminates the possibility of field sealing any disturbed or improperly sealed sash corner joints. The recessed rabbet design also requires flow-in-place sealants. Since the shims must be forced in place after the glass is set, they must be precleaned to prevent contamination of the cleaned glass or sash sealing surfaces.

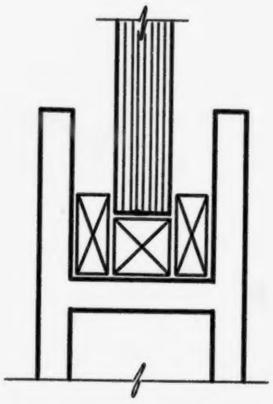

Figure 9 -- The recessed or groove glazing rabbet design.

JOINT DESIGN CRITERIA

From our experience, we propose the following joint design criteria as being most important factors in achieving successful glazing and sealing.

1. The rabbet design must present maximum opportunity to handle and set glass lights without damage. This assumes that reasonable care will be exercised by the glazers while maintaining productive glazing rates.

2. The finished job must be neat in appearance and must stay weathertight, preferably with no maintenance, but acceptably with a reasonable, regular maintenance program.
3. Adequate joint dimensions must provide for adequate glass edge encasement, sealant width and depth, and accessability for cleaning and sealant application.
4. Joint design must give freedom to consider the use of all types of sealants, (bulk, tape, flow-in-place, or compression gaskets) in accordance with compound manufacturers' recommendations.
5. The design should require a minimum number of sealing operations.
6. The design should incorporate a functional weep system.

Success can be insured only by complete specifications, including the most minute sash design, glazing, and sealing details, and with the full cooperation of the owners, architects, contractors, and suppliers to see that the specifications are enforced.

Metal and Glass Joint Sealants from a Fabricator's Viewpoint

By Jack M. Roehm, Kawneer Company

Abstract: For the fabricator, sealants are the most critical item in metal and glass curtain wall assembly. Factors affecting performance are wall materials and components, expansion and contraction, load, weather, and environment. Types of sealants used today in metal curtain wall construction are evaluated. Neoprene structural gaskets are rated excellent and are increasing in popularity. Vinyl gaskets are of lower cost, easier to install, but not satisfactory for structural uses. Polysulfide liquid polymers give outstanding performance but are high in cost. One-part silicone base sealants and butyl tapes are also good.

FROM THE POINT OF VIEW OF THE FABRICATOR, sealants constitute the most critical item in the erection of a satisfactory metal and glass curtain wall. Sealants must accommodate a variety of conditions within a building, while at the same time making successful adjustments to the continually changing environment which surrounds them.

Let's take a brief look at the conditions within the building and the environment, in order to set the stage for a discussion of the sealant problem.

FACTORS AFFECTING PERFORMANCE

The first condition encountered is the difference in the materials used in the wall and the building structure. The latter is generally structural steel or reinforced concrete; the framework of the former is generally aluminum or stainless steel. Within the metal wall framework there is glass, and there are panels which may be made of steel, stone, aluminum, ceramics, or a number of other materials. In addition to fixed lights of glass, there will be operating windows. All of these wall materials and components must fit together, be anchored to the building structure, and form a weathertight envelope. They must do this in spite of the fact that components can only be manufactured within certain tolerance ranges, and the building structure can only be erected within certain still wider tolerance ranges.

ROEHM, JACK M. Vice President, Research & Development, Kawneer Company; member, American Institute of Electrical Engineers, American Society of Mechanical Engineers, BRI; President, National Association of Architectural Metal Manufacturers.

Then, what about the environment within which this building with its envelope must live? Temperatures on the outer surface can range from well over 100° F to well under 0° F. All of the elements of the building must expand and contract with these temperature changes. Since the elements are of several different materials, the amounts of expansion and contraction vary. The sealants tying the elements together must change their dimensions, going into compression, bending, shear or tension, to accommodate these changes without permitting air or water to penetrate.

Impose upon this the loads resulting from the action of wind, and it becomes apparent that the sealant must be considered sort of a super-product. Not only must this product perform its functions faithfully, but it must be able to resist for a long time -- many, many years -- the effects of solar radiation, atmosphere, moisture, industrial dusts, freezing and thawing, and other things which mitigate against a long, healthy life. It must also do all this without ever failing in its performance.

TYPES OF SEALANTS FOR CURTAIN WALLS

Now let's consider some of the different types of sealants used in metal curtain wall construction today. We will devote no time to putty or any of the many oil-base compounds used in calking, nor will we devote any time to the chemistry of sealants. Rather, we will discuss the practical application of sealants to curtain wall construction; some of the experiences we have had with these sealants; and limitations imposed on their application.

From the fabricator's point of view, a sealant is anything from a neoprene gasket, which structurally connects glass, mullion, and panel, to the liquid polysulfide polymers which are applied as relatively high viscosity liquids and cure as rubbery solids, filling the space between metal and glass and adhering firmly to the surfaces.

Neoprene Gaskets

The neoprene structural gasket has been in use for at least a decade. At the present time, its use is increasing in popularity. By and large, the experience with this type of sealant has been excellent. Prior to its use in building construction, it had for many years given satisfactory performance in the automotive field in the sealing of windshields and rear windows. The use of neoprene gaskets in building construction is quite a different thing from automotive use, however. Much larger lights of glass must be supported, and the tolerances to which the gasket must accommodate itself in a building are much greater. Square corners are the general rule, instead of round. These differences impose more severe conditions on the gasket.

In a typical installation, the gasket is slipped over a fin on the mullion, the glass is inserted, and the zipper is zipped in place. This process is illustrated in Figure 1. If everything is done properly--the neoprene extruded with the proper materials to the proper durometer, the glass cut so as to fit closely within the gaskets, the glass thickness reasonably well within tolerance--the resulting wall will be one of the finest it is possible to build. Air and watertightness will be excellent.

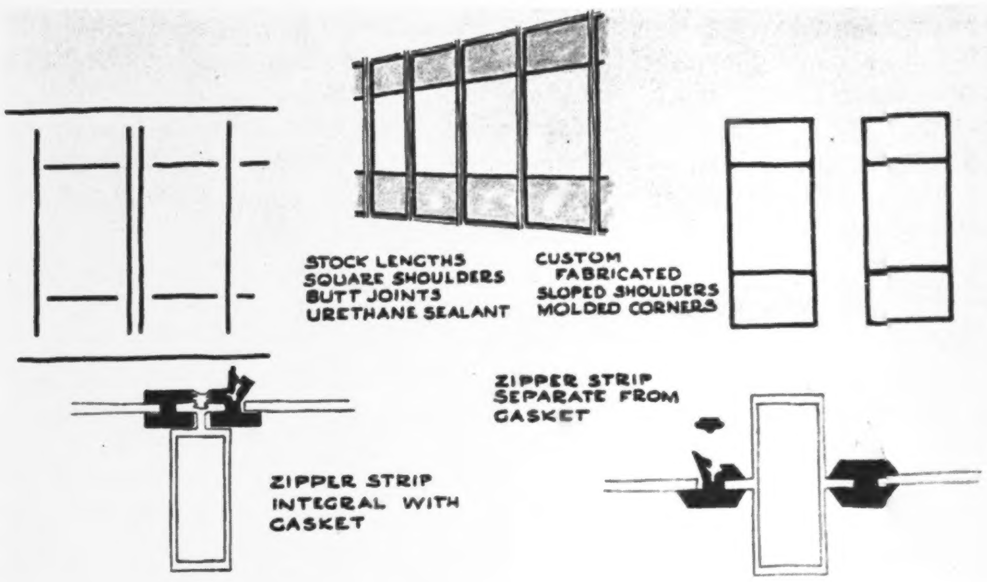
STOCK LENGTHS
SQUARE SHOULDERS
BUTT JOINTS
URETHANE SEALANT
CUSTOM
FABRICATED
SLOPED SHOULDERS
MOLDED CORNERS
ZIPPER STRIP
SEPARATE FROM
GASKET
ZIPPER STRIP
INTEGRAL WITH
GASKET

Figure 1--Metal to glass seals (structural gasket, curtain wall).

Neoprene structural gaskets for metal curtain walls are installed in two ways. One is to make a rectangular framework by vulcanizing the four corners of the gaskets, and then insert the gasket assembly into the metal framing elements of the wall. The second is to cut the gaskets to length in the field, insert the gasket into the metal framing with longitudinal compression, and effect butt joints where the horizontal and vertical gaskets come together. A urethane compound is used to seal the joints tightly. Both of these methods have been used with success. The first involves more factory assembly, with tighter tolerances; the second permits greater variation in tolerances and involves more on-the-site assembly work.

What are some of the characteristics of this type of joinery?

1. The neoprene gasket, being resilient, does not restrain glass edges as rigidly as the more conventional systems; hence the glass will tend to deflect more.
2. Glass dimensions are critical. If glass is cut undersize, the danger of blow-out is increased.

3. A loose grip on the glass, because of poor tolerance control, can result in excessive clearance between glass and rubber, and allow the glass to deflect excessively, with consequent danger of breakage.
4. If grippage on mullion fin is not adequate, the gasket will tend to roll around the fin, allowing the glass to deflect excessively.
5. Neoprene becomes hard in cold weather, making glazing extremely difficult unless provision is made for heating the gaskets before installation. In fact, with the materials presently available, it is absolutely essential that the neoprene be kept well above freezing temperature; otherwise the job of glazing becomes extremely difficult, if not impossible.

What the fabricator would like to have in the way of an improvement to neoprene is a material which would retain its flexibility well below freezing temperatures, so that erection work could proceed without difficulty or delay. Better control of production tolerances is another area requiring attention. Out-of-tolerance gaskets become difficult to handle and give erratic performance. In spite of these criticisms, it should be re-emphasized that structural neoprene gaskets, when properly installed, result in one of the finest types of curtain wall construction known.

In addition to the structural type of gaskets, neoprene gaskets are used extensively to form seals between metal and glass, and between metal and metal. Typical of the latter case is the operating window where the surrounding of the operating sash must seal solidly against the window frame. This is illustrated in Figure 2.

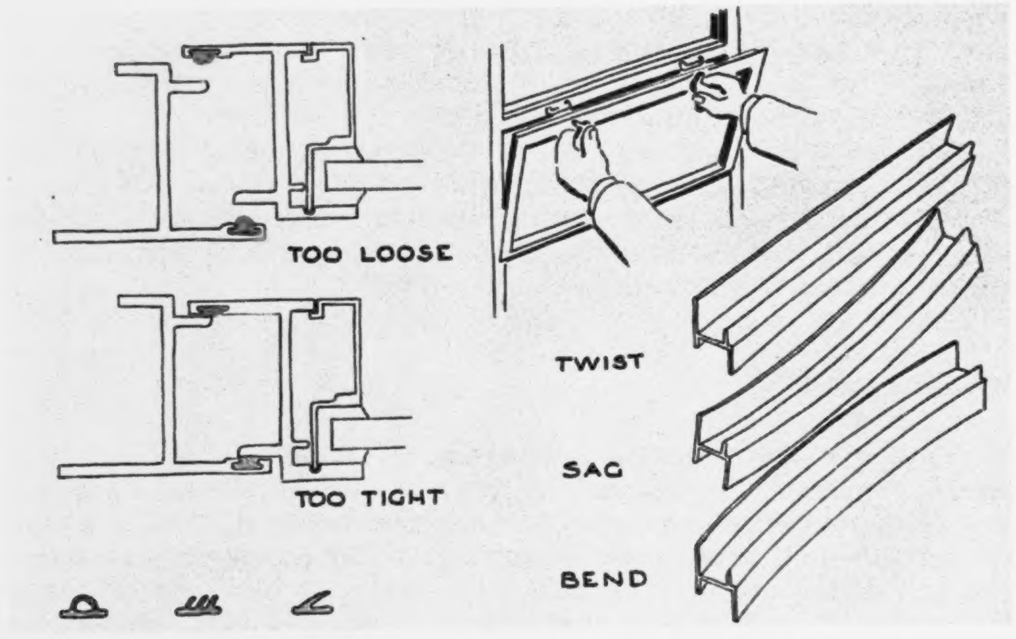

Figure 2 -- Metal to metal seals (hopper windows).

Neoprene is particularly good for these applications, not only because of its long life but also because of the fact that neoprene retains a large percentage of its resilience, even though it is kept under compression for many years. This is important if a window is to resist infiltration of air and water satisfactorily on a gusty, rainy day.

One of the problems with neoprene is that of providing sufficient elasticity to permit a large ratio of uncompressed thickness to compressed thickness. The gasket must seal tightly, but it must not exert so much force that a person is unable to close a window. Mechanically, a gasket can be considered a spring, and ideally, it must be a spring with low spring-rate.

Variations in clearance between elements being sealed are often relatively large, owing to normal manufacturing and assembly tolerances, plus distortions which occur in installation. This means that the gasket will be under very low compressive force at one point, and very high compressive force at another, and yet it must seal satisfactorily under both of these extreme conditions.

The need for a low force-level and a low spring-rate creates the biggest problem for gasket designers. Many designs have been developed to solve this problem, with hollow shapes and fins among the most common solutions. Neoprene sponges would appear to offer the best answer, but much development work still remains to be done in this area.

Before closing the discussion on gaskets, and the problems created by building tolerances, let us consider the case of the vertical, center-pivoted window, a gadget which has become very popular with architects in recent years. Figure 3 illustrates a case in point. It is possible to wash this type of window from the inside. They must, in most cases, pivot 360°; therefore the gasket must slide past the frame, and yet seal perfectly when the window is in normal position. There is no opportunity to compress the gasket between metal faces as we do with projected windows.

Another problem occurs when the window is not square with the frame, a problem which exists most of the time. At one point there is excessive clearance; at another, insufficient clearance. Producing a gasket that is versatile enough to take care of this problem borders on the impossible.

Vinyl Gaskets

Vinyl gaskets have also been used successfully for a number of years. However, they cannot be used as structural gaskets in the way that neoprene can, nor do they give the best results where spring-like properties are essential to satisfactory performance. Being plastic, vinyls have cold flow characteristics which make them unsuitable for such applications. Also, they contract a great deal when the temperature drops and, unless properly installed, will pull away at a junction point and provide an opportunity for leakage.

On the other hand, vinyl gaskets are lower in cost than neoprene, are easier to install and, with proper design, can be used for many applications with entirely satisfactory results.

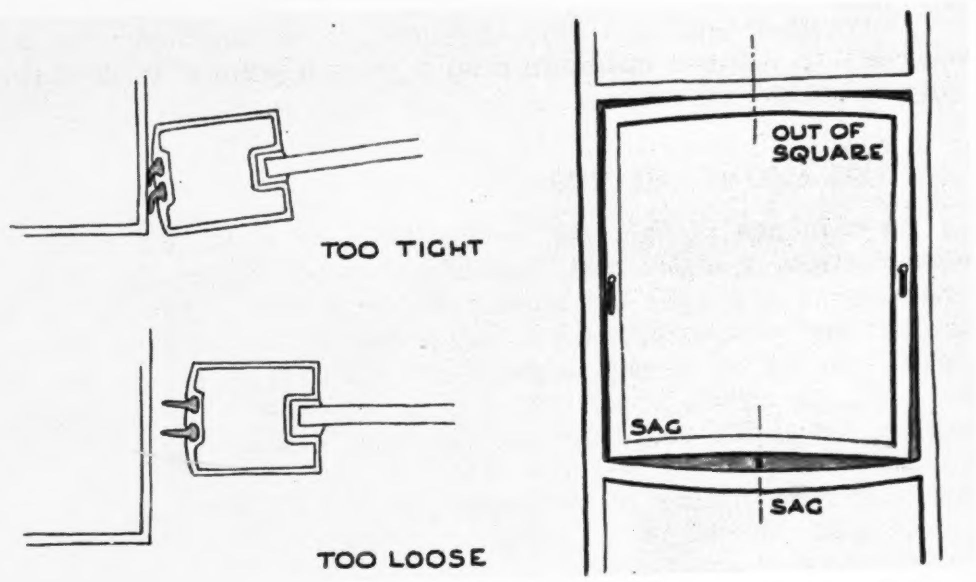

Figure 3 -- Metal to metal seals (center-pivoted windows).

This paper has dealt mostly with rubber-like gaskets, which may seem strange to those who think of sealants in terms of compounds squeezed from calking guns. This was done deliberately, in order to reflect at least some of the thinking of a metal fabricator. It would be well, in our opinion, if sealants could be handled somewhat like metals; that is, they could be extruded to desired size and shape within reasonable tolerances, cut to size, readily assembled into panel units, and erected without further fuss or muss into the wall. However, the problems of sealing curtain walls are not so simple that all of the solutions can be found in rubber or plastic gaskets.

Polysulfides, Silicones, and Tapes

For joint sealing and glazing, where high adhesion is required, and where repeated cyclic movement in the joint is anticipated, the two-part rubber-base compounds, polysulfide liquid polymers, give outstanding performance. Polysulfide sealants now have a number of years of most successful experience behind them, but are somewhat high in cost. Handling, storage, and application require strict adherence to certain procedures, but the end-result appears to be worth the cost and trouble.

One-part silicone-base sealants also have been used with good results. My own company has had good experience with this type of sealant. Installers prefer the one-part to the two-part because of its easier handling.

Butyl tapes are another type of sealant which can be relied upon to do a fine job. Often, tapes are used in combination with neoprene gaskets.

Polysulfide sealants also are used in combination with other sealants to achieve optimum results from a point of view of economy and performance.

TESTING AND STANDARDS

As a means of checking performance of metal and glass wall construction, a static test chamber is used (Figure 4). This test chamber is a simple but most effective means of checking a wall for air and water infiltration. The pressure in the chamber is reduced, so as to develop a pressure differential across the wall; the wall, in effect, being one side of the chamber. Air and water infiltration at different pressure differentials are measured through suitable instrumentation. The Metal Curtain Wall Division of the National Association of Architectural Metal Manufacturers has established standards of performance which should be expected from good wall construction.

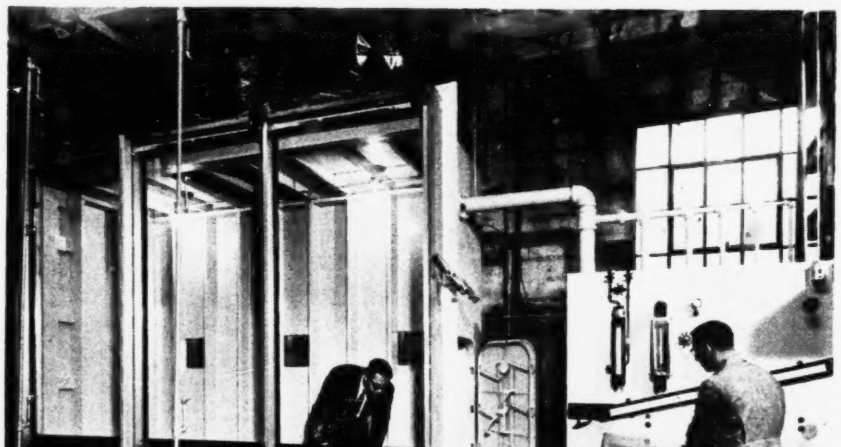

Figure 4 -- Static test chamber.

The success or failure of a metal curtain wall will often be determined on the drafting board of the architect. It is his responsibility to specify the sealant. If his office is large enough, he will have the help of his own specification writer. If his office is small, he will have to depend on data supplied to him by the wall fabricator, the sealant manufacturer, or preferably, data published by the recognized industry association.

The Metal Curtain Wall Division of NAAMM, with the help of manufacturers of sealing materials and in cooperation with other associations, has prepared a guide for assisting in specifying the proper type sealants for particular applications. In addition to the guide, standards for different types of sealing materials have been established. By demanding that materials be supplied in accordance with these standards, the metal wall fabricator and erector can be sure that he will meet the architect's requirements for performance, when the wall is finally in place.

THE FABRICATOR TODAY

In summary, the fabricator, after a number of years of experience with different sealing materials, is developing a good understanding of the capabilities and limitations of the materials available to him. He is becoming more proficient in designing his products to take advantage of the good properties of the materials. He is able, through his trade associations, to spell out performance requirements, and he is similarly able to specify standard tests for checking performance. He has received whole-hearted cooperation from the manufacturers of sealing materials. Through this cooperation better materials are being developed.

We have come a long way in a relatively few years. Sealants will constitute the most critical item in a metal and glass wall assembly, but the materials and techniques available to us today make it possible to erect a wall with no question as to its performance.

Open Forum Discussion

Moderator: Raymond J. Schutz, Sika Chemical Corporation

Panel Members: Messrs. Hunt, Roehm, and Valentine

Mr. Schutz: Do you recommend the use of primers when using a sealant with concrete?

Mr. Hunt: I certainly do. It's always necessary to use a primer with concrete, masonry or natural stone.

Mr. Schutz: How do you compare the performance of compression gaskets to that of the cured, flow-in-place sealants?

Mr. Valentine: I'd like to answer that in two parts, one having to do with the initial installation problems, and the second with the long-range performance. The compression gasket achieves its sealing power by the application of uniform pressure from the stop to the gasket, and transmits it through the glass to the other lip of the gasket. With most of the available commercial sash, either because the stops are willowy or because the screw spacing is too large, the actual compression pressure is only in the screw areas. The stops bend, and literally relieve the pressure between screw areas, so that you are not assured of an initial seal in some installations. In fact, we have found it necessary on several installations, since the gaskets were there on the job, and the sash was also there, to apply a flow-in-place sealant to make the initial seal. In contrast, when using the flow-in-place sealant originally, the glass is normally centered by means of continuous shims on both sides, and the sealant then flowed into the indoor and outdoor voids thus created. Provided these voids are sufficiently wide to permit filling them from the bottom out, the tolerance problem is eliminated.

As to the long-range performance, the stops will bow to a certain extent between screws. If you only have enough compression between screws to make an initial seal, and if there is any compression set in the materials, or sufficient movement of the glass under wind loads, this can open the gasket and permit water leakage. The polysulfides, or flow-in-place sealants, actually bond to the metal and to the glass, and when movement occurs the membrane stretches across the cavity to keep water out. The difference is that one adheres, and the other is simply a mechanical seal. If the forces are present that will eliminate the compression on the seal, there can be water leakage.

Mr. Schutz: Is there a limitation on the size of lights of glass which may be satisfactorily used with neoprene structural gaskets?

Mr. Roehm: The major glass companies publish tables, and I believe those tables are also used by the Flat Glass Jobbers' Association, giving glass dimensions, the total glass area which may be used under given total loads. These loads per area, as far as I can determine, are based on glass being held reasonably rigid around all four sides of a square light, in other words, a plate fixed on all four edges. With neoprene gaskets, the loads published by the glass companies will be the same if the neoprene is properly installed, and if it is mounted on rigid framing on all four sides. A difference occurs when, for example, three lights are installed within one framework: a light panel at the top which may be a 1/4 in. of colored glass, then the regular glass, and then a bottom panel which may be a 1/4 in. masonite panel with porcelain facing. In this case, the top and bottom panels will deflect about as much as the glass. The glass in the center panel is no longer supported on all four sides by a reasonably rigid frame. Therefore, it tends to bow out in a cylindrical fashion, being restrained on two sides. Our experience shows that you need a type of load deflection curve different from those which are published as the normal standard to take care of this situation.

A. P. Yundt, Bird and Son, Inc.: Have you any comments on the use of epoxy mortars for sealants on concrete panels, for concrete-to-concrete joints to make a monolithic construction of large size, at least before expansion-type joints are required?

Mr. Schutz: I believe the question means, can you make a large panel out of small units, and how large can it be before you need a flexible joint?

Mr. Hunt: It could be done, but it probably would be quite expensive. You would have to be sure that the panels fit together very accurately because epoxy, as an adhesive, works very well, but the two materials being bonded together must fit very closely. Actually, it then becomes an uneconomical application. There are other ways of doing it just as well. As far as panel size is concerned, you're more limited by the matter of transportation than anything else. Generally, a panel that is more than 8 feet in one dimension is difficult to transport from the point of fabrication to the job. In other words, you can use panels 8 feet wide and 20 feet or 30 feet long. In one panel job I know the panels were 66 feet in length, but one dimension must be held to a point where you can move the panels down the road or through an underpass.

Roscoe Smith, Office of Douglass Orr: To obtain better performance of sealants, should proposed glazing details be as recommended and/or approved by the glass manufacturers?

Mr. Valentine: While the glass manufacturer, or at least his literature, should be consulted for the proper setting conditions to make his glass products perform, the best glazing details to insure the performance of the sealants should be a cooperative effort among the sash manufacturers, the sealant manufacturer and the glazing contractor. If all 3 have an opportunity to review the details before the glazing begins, each can comment on the effect that the work and/or products of the other two have on his part in the glazing detail. If changes are necessary, the best time to do it, obviously, is before glazing begins.

J. D. Hanft, Turner Construction Company: Regarding neoprene seals in hopper window installations, what causes the neoprene gasket to pull out of its rabbet, and how may this be overcome?

Mr. Roehm: I can only say that improper design must cause it to pull out of its rabbet. It would be possible to use an adhesive to glue the neoprene in place, and then I don't think it would pull out of its rabbet, if we're talking about the compression type of gasket between a window and its frame.

It's perfectly all right to use adhesive to secure these gaskets. Some designs specify that you glue in the neoprene gasket.

W. H. Kuenning, Portland Cement Association: Have you had any experience with bitumen-impregnated polyurethane foam gaskets?

Mr. Roehm: We have not had enough experience with those for me to comment. We are testing them in the laboratory and for certain applications, I think they have promise.

N. J. Sullivan, E. I. duPont de Nemours & Company, Inc.: Are there, for concrete, experiences of record in which an oleoresinous calking compound has been used successfully, continuously immersed? Of what significance are temperatures up to 180° F for this condition?

Mr. Hunt: I have no knowledge of such an application. That doesn't mean that it hasn't been used that way, but I just don't know of one.

Mr. Schutz: Would you use one?

Mr. Hunt: I would be a bit doubtful about it myself.

S. B. Twiss, Cycleweld Division of Chrysler: In the case of neoprene gaskets, do you use, in addition, liquid sealants or adhesives? If so, what types are used? If not, what are the objections to their use?

Mr. Roehm: We do not use any liquid sealant in combination with the neoprene gasket where the gasket grips the glass or metal. We have used a urethane compound where we butt the neoprene joints. The only objection to using a sealant with the gasket is the fact that it's an extra material and it requires an extra handling operation. If we start off with a neoprene gasket, with proper tolerances on the metal and the glass, build our metal and glass assembly and test it, we find that it tests out just as well as the neoprene with a sealant added. On the other hand, if you use a sealant, you can permit greater variation in tolerances between the fit of the metal and the neoprene and the glass than you can without the use of sealant. I would say the extra operations, the extra labor involved, are the main objections to it. It could, perhaps, be a safety factor, but we do not think it is necessary. In the building field, the glass is always applied at the building site, at least in our own experience, in contrast to the automotive industry where the glass is applied in a factory. In the automotive field, a sealant is used with the neoprene gasket to hold the glass. However, if the materials are in proper tolerance, it's not necessary, and it adds cost.

Mr. Valentine: I agree that if the tolerances are properly controlled, and the formulation of the rubber gasket material is of such nature that it can be compressed and will achieve a good mechanical seal, it is probably cheaper in the long run to eliminate the sealant. But, in a very practical sense, when you're buying gaskets from one supplier, a metal frame from another, and the glass from a third, and they meet on the job, it is not always possible to control these tolerances. We have had to use sealants, especially in corner areas where vulcanized corners or preformed corner joints cause an offset which increases the amount you have to compress before you even touch the glass. In such cases we have had to use them because water leakage tests, hose tests or full-scale mockup tests, have indicated that the tolerances haven't been controlled well enough to do without them. In those cases, we use a liquid butyl.

R. L. Malobicky, Pittsburgh Plate Glass Company: Is there any difference in the sealing performance of the one-piece structural rubber gasket as opposed to the one incorporating a separate filler strip?

Mr. Roehm: We have not been able to measure any difference in the performance of a separate filler strip and the one-piece gasket. The one-piece is used as a matter of convenience in our case, so that we have only one gasket to handle and this eliminates the possibility of having something missing. Also, we think a one-piece is somewhat easier to glaze than a two-piece.

C. H. Kline, C. H. Kline & Co., Inc.: What types of primer do you recommend for concrete panels before application of the sealant?

Mr. Hunt: The primer recommended by the manufacturer of the sealant is the best thing to use.

W. L. Williams, Enjay Chemical Company: As a curtain wall fabricator, what do you consider to be the most important performance characteristics in elastomeric structural gaskets?

Mr. Roehm: To hold tightly to the members it's supposed to join, to permit no air or water to go through the joint, and to do these things for the life of the building.

Mr. Williams: What percentage of the average curtain wall cost does the structural gasket represent?

Mr. Roehm: That's an easy one to evade, because it depends on how the architect designs the wall. On some walls, exclusive of the cost of the glass, the cost of the gasket is approximately one third of the total cost.

G. M. Lewis, Cafritz Company: Please recommend a method or material for removing oil from stone in preparation for application of two-part polysulfide calking.

Mr. Hunt: It can be removed with some solvents, but often, if there's very much of it, sandblasting will be necessary.

Mr. Schutz: Would you use a solvent for removal of oil on concrete?

Mr. Hunt: If you can get it to work, yes. It's hard to get the oil out of concrete. It gets in pretty deep.

Mr. Schutz: Would you recommend sandblasting or solvent?

Mr. Hunt: Maybe both.

Mr. Valentine: For removing the oil from metals, we suggest a 50-50 mixture of xylol and acetone, the xylol to cut the oil, and the acetone to dry up some of the moisture vapor present. That's our standard recommendation for cleaning metals for all sealants.

Mr. Schutz: The same would apply for glass which is not clean, of course.

Mr. Valentine: For glass we recommend a water slurry of 4F pumice. This has several advantages. One is that it's one of the best methods of cleaning glass, and secondly, if the dried pumice film is left on, and only removed immediately before setting the glass, it prevents further contamination. Also, when you put the glass in the opening, you know whether it's clean because, if you still see pumice on it, you haven't done a thorough job of cleaning.

Mr. Lewis: Please describe a method of filling poorly fitted joints in aluminum sash without affecting the appearance.

Mr. Valentine: I don't think there is an easy method. It depends on the width and the depth of the cavity. If the joint is wide enough, I would mask both metal surfaces, and clean the inside of the crevice as well as I could to permit good adhesion, using a solvent mix. Then, it should be wiped with a clean, dry cloth, and the sealant material gunned in. Then tool the sealant much the same as you would tool a masonry joint to insure that you've thoroughly packed the crevice. If the sealant happens to be a polysulfide, before the material cures, in fact, immediately after tooling, remove the masking tape. This should provide a nice, flush appearance. However, if the depth is great in relation to the width, and the cavity is rather wide, you'd have to put in a filler shim: a continuous shim in the base of the crevice to back up the polysulfide sealant and cause it to expand under gun pressure, and wet the metal surfaces. If it's only a hairline crevice, I think you're wasting your time to fill it, because it's almost impossible.

Alex O'Hare, Miracle Adhesives: What type of calking was used on the Denver job originally?

Mr. Hunt: It was an oil base material, one of the better types.

Unsigned question: You referred to a static test chamber as the device used in checking performance of metal and glass wall construction. Explain why you use static and not dynamic tests.

Mr. Roehm: There's been a debate raging in some circles for several years now, on whether you should use static testing, which means setting up a chamber in which you impose a pressure differential across a wall by evacuating the chamber; or whether you should use a dynamic method, which means mounting the wall on a box, getting an airplane engine and propeller, and blowing wind on the wall. The latter makes a very spectacular show, but the dynamic method, the airplane engine test, does not seem to be as rugged as the static test. There have been walls, in our experience, that have passed the dynamic test, but when we have exposed them to the static test, they leak rather badly. For that reason, a number of us, wanting to play it as safe as we can, knowing the expense involved if you have to go back to repair a leaky wall, have chosen the static test as the best means of checking wall performance. In other words, the static test appears to be more rigorous than the dynamic test. Of course, we may be kidding ourselves about this. We may be exposing our walls to a more rugged experience than they'll ever have to endure in use. The whole area of wall testing needs a lot more work and study before we will finally have arrived at a point where we are sure our laboratory work is correlating well with field experience. But, at the present time, at least in our opinion as one company, we think the static test is the safer test for us to use on walls.

Mr. Valentine: We, too, use the static load test as a control test. We prefer it to the dynamic. For one reason, it's very difficult to determine where to measure the air pressure as the control element in a dynamic test. There is a considerable decrease in the velocity of the air from the propeller to the wall surface. At the wall surface, there is turbulence which can give a wide range of velocities across the wall area. This latter point depends to a great extent on the wall design, i.e., module size, mullion depth, etc. So, you seldom know at what velocity you are testing. Secondly, static loads permit you to hold a pressure for a sufficiently long time, to make the measurements that you want to make. If they happen to be strain measurements, and there are quite a few gauges around the area, it takes some time to read them. You must keep the load as constant as you can so that you get all the readings under essentially the same conditions. As Mr. Roehm said, the static is, in our opinion also, the roughest of the two tests, and if you have exposed the wall to the roughest test, you can be reasonably certain that it's going to perform well.

G. M. Lewis, Cafritz Company: Please comment on the use of the two-part polysulfide as a joint sealer in swimming pools constructed of reinforced concrete.

Mr. Hunt: It's used quite a lot, although oftentimes they just put in a waterstop of polyvinyl chloride or something like that, and don't go to the expense of using a polysulfide sealant. However, it's a good sealer for swimming pool walls.

Mr. Valentine: If we were asked to specify the application procedure for sealing swimming pools with polysulfide, it would be something like this. Using a wire brush, brush the crevice free of any dust, dirt, or contamination on the surface. Apply a suitable primer to the concrete surfaces as recommended by the polysulfide manufacturer, since he alone knows what's in his compound and what will work best with it. If the crevice is very deep, both from an economic standpoint and from the standpoint of performance, you should back it up with some sort of a filler strip (we would suggest a neoprene filler strip) so as to provide a three-sided cavity to seal. Then, thoroughly mix the polysulfide, gun it in, finish it off again with a tooling operation, so that you get rid of any air entrapped in the seal, and that should do a good job.

Unsigned question: Would you recommend chamfered edges on glass panels when used in conjunction with gasket sealants?

Mr. Roehm: We recommend that you at least run a stone down the side of the sharp edges of glass. They don't necessarily have to be chamfered, but we prefer to take the sharp edge off.

Mr. Valentine: The strongest glass edge is a clean-cut edge. Anytime you abrade it for the purpose of getting rid of that sharp edge, you can create imperfections in it that are stress-raisers, and especially in the case of heat-absorbing glass, this can produce some breakage. To reduce edge sharpness, we would probably suggest you might tape the glass edges but never abrade them.

Mr. Roehm: Let me carry that a little further. Quite often you see glaziers take a pair of pliers, if the glass is not cut right, and pinch off the edges. There are all kinds of terrible ways to bring glass down to size. We would prefer a good clean factory cut over anything else.

Mr. Valentine: The nipping procedure referred to by Mr. Roehm to bring glass down to size has been used for years. I've seen some glass that was set 25, 30 or 40 years ago that looks like the glazier chewed off the edges and it had no effect on performance, but he was using very small lights in a very rigid frame. It was either plate or window glass, but had no heat-absorbing characteristics. Today, with increasing glass sizes and new specialty glasses, edge protection becomes a more important factor.

Mr. Roehm: I concur with you a hundred percent. Anytime we use anything but clear glass, we discover that the glass manufacturers are still learning quite a bit about their product.

Mr. Valentine: It's a standard policy that we'll produce heat-absorbing glass in any size that it is physically possible to make, and have no qualms about its performance, so long as the edges are clean cut. That's the only stipulation.

Mr. Schutz: In other words, you prefer that glass be clean-cut.

Mr. Valentine: It's the strongest. Anytime you sand the edges, you put in incipient vents.

Unsigned question: Is there a real problem of ultra-violet light affecting adhesion of polysulfide sealants to the underside of the glass, or is this just an unrealistic laboratory aging test?

Mr. Valentine: No, I'd say there is, or at least was a problem. This is not just laboratory talk. For example, most laboratories test the adhesion of polysulfide sealants to glass with the glass-sealant interface exposed directly to the ultra-violet source to determine the resistance of the compound to ultra-violet attack. This has to be done; otherwise too many jobs may go up before you know whether the sealant is a success or a failure: however, that's not the extent of the testing. We have actually glazed frames and exposed them in Florida and within 6 months, in some instances, there was total loss of adhesion of the sealant to the glass. Now, before anyone gets too excited, let me say that these were very early compounds, very early formulations produced some years ago. They were compounds that didn't check out well on the ultra-violet tests when the inner face was exposed directly to the source. We run a constant program of evaluating commercially available sealants, among them the polysulfides, and have noted a remarkable increase in the ultra-violet resistance. We don't feel it's a major problem any more. The primary value of the laboratory testing was that we did discover that this problem existed, so the formulators could go to work and solve it.

H. F. Wakefield, Consultant: On the Des Moines structure, a "good calking compound" was mentioned. It was also called a "sealant." What was the material, a calking compound, or a sealant?

Mr. Hunt: It was an oil-base calking material.

J. M. McClellan, Wyandotte Chemical Company: Please identify the urethane sealant referred to in your first illustration.

Mr. Roehm: The urethane sealant that we use with this gasket is a product of E. I. du Pont de Nemours & Company, and I don't know exactly how they identify it. Someone from there could tell you more specifically what it is. It's a black goo you put on with a putty knife, and it cures. Actually, you can't say that it's an adhesive, but it adheres well enough to make a very good joint after it hardens.

N. Healey, Minnesota Mining & Manufacturing Company of Canada: Are special polysulfide sealants needed for heat-absorbing glass?

Mr. Valentine: No. Heat-absorbing glass will, on exposure, attain higher temperature than regular plate glass, but not so high as to affect the sealing effectiveness of the polysulfide.

Mr. Healey: Does heat-absorbing glass affect the standard available materials?

Mr. Valentine: Not to my knowledge.

Sealant Criteria Based on Recent Research and Performance Experience

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A Theory of Adhesion for Joint Sealants

By J. J. Bikerman, Massachusetts Institute of Technology

Abstract: Joint sealants are similar to structural adhesives, their principal difference being the fact that they fill a space of almost constant volume. In terms of final strength, adhesive joints may be classified as hooking or mechanical interlocking joints, where rupture is determined by the tensile strength of the fibers or the solid adhesive; proper joints, where rupture may occur in the adherend or adhesive; and improper joints, where rupture occurs in a weak boundary layer. A separation does not occur exactly along the interface; therefore, the forces of molecular adhesion across this interface do not determine the experimental strength of adhesive joints. In the case of poor sealant performance, it is necessary to find out whether the sealant is a good adhesive, whether the joint is proper, and if it is improper, what is the cause of the weak boundary layer.

JOINT SEALANTS DIFFER from the ordinary adhesives in two respects. First, they are not supposed to withstand strong stresses applied externally, but this difference is not basic, because dimensional changes caused by fluctuations of temperature and humidity may result in stresses just as great as the external ones. Second, they fill a space of almost constant volume, in contrast to the usual adhesives, which customarily solidify at a nearly constant pressure. This peculiarity has two consequences:

1. If V_1 is the volume occupied by a unit mass of an adhesive before setting, and V_o that after setting, as a rule $V_o < V_1$. If the adhesive is forced to solidify without marked volume change, the solid adhesive remains in that state of stress corresponding to its expansion from V_o to V_1. To render these stresses small and inoffensive, we can either make the difference $V_1 - V_o$ small, or select an adhesive in which the major part of the contraction takes place when the viscosity of the adhesive is still small and rapid relaxation of the shrinkage stresses is possible. Apparently the latter device is more common in industry than the former.
2. Because no adhesive is squeezed out of the clearance, there is a danger that the air displaced by the adhesive from the

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BIKERMAN, J. J. Supervisor, Adhesives Laboratory, Massachusetts Institute of Technology; member, American Chemical Society, British Society of Rheology, Society of Rheology. The oral presentation of Mr. Bikerman's paper was made by Daniel K. Donovan, Research Engineer, Larsen Products Corporation; member, BRI.

valleys on the adherend surface may remain as minute bubbles near this surface. To render these bubbles innocuous, an adhesive having a high total relative elongation appears to be suitable.

Sealants are used to seal, i.e., they should not contain cracks or pores reaching from one end to the other. This, however, is not a totally independent condition, because an adhesive impaired by cracks and pores is not likely to remain in one piece during expansion and contraction cycles produced by environmental variations.

It appears from the above discussion that sealants are a class of adhesives not very different from the rest. Thus we may expect the main rules for structural adhesives to be valid for sealants also.

TYPES OF ADHESIVE JOINTS

For people interested mainly in the final strength of adhesive joints after complete setting, these may be classified as hooking, proper, and improper joints.

Hooking or Mechanical Interlocking Joints

Joints whose strength is predicated on hooking or mechanical interlocking are common when the adherends are porous, as are, for instance, paper and cardboard. Presumably in joining wood to wood or concrete to concrete, hooking also is important in many instances, but no relevant and conclusive experiments are known to the author.

The mechanism of these joints is particularly simple. During the application, the liquid adhesive flows around the fibers. During the next stage, which is setting, it solidifies, forming solid hooks or loops. Thus, when an attempt is made to separate two fibrous bodies glued together with a set adhesive, no separation is possible unless either the adhesive hook or the fibers break. It is clear that the breaking stress of such joints is fundamentally determined by the tensile strength of the fibers or of the solid adhesive, whichever is weaker.

Proper Joints

The last statement is true also for proper joints. These are common between non-porous adherends such as metals, glasses, and plastics. In these joints, solidified adhesive is in intimate contact (on the molecular scale) with the adherend, without any weak material covering the interface of adherend and adhesive. When the joint is broken by an external force, rupture proceeds either in the adhesive or in the adherend; as a rule, of course, in the weaker material.

Suppose that the adhesive is the weaker material and gives way before the adherend. In this case, the experimental breaking stress is closely related to the tensile strength of the adhesive material. We may say that a butt adhesive joint is a tensile testing specimen for the adhesive, the difference between the two tests being that, in the standard tensile arrangement, the sample is clamped in the holders, while in the adhesive joint it is glued to them.

This difference results in a difference between the joint strength f and tensile strength f_M of the adhesive in bulk. Also, in joints of the hooking type, in an analogous manner, f may be different from f_M. The ratio f/f_M may, in simple instances, be expressed in the form

$$\frac{f}{f_M} = \frac{\beta_o(\xi - \beta s)}{\alpha\beta(\xi - \beta_o s_o)} \qquad \text{Equation 1}$$

In this equation, ξ is the theoretical cohesion of the adhesive, α is the stress concentration factor due to the difference between the mechanical properties of the adherend and the adhesive. Further, β and β_o are the stress concentration factors due to the inhomogeneity of all solids. Because, generally, the solidification of the adhesive between the two adherends takes place in conditions different from those of the solidification of the adhesive in bulk, factor β for the joint generally is different from factor β_o for the bulk. Finally, s and s_o are the shrinkage stresses, already mentioned, for the adhesive in the joint and in bulk. Again, s usually will be different from s_o because the solidification conditions are not identical.

In joints judiciously designed and made, α is not significantly greater than unity, s is small, and β either less than β_o (in thin joints) or practically equal to β_o (in thick joints). Thus, f is slightly greater than, or nearly equal to, f_M when this is determined on well-annealed specimens. Several instances of this behavior are known; e.g., for soldered joints and joints between metals and glasses in which polyethylene is the adhesive. When $f > f_M$ or at least $f = f_M$, we may conclude that we get the ultimate out of the adhesive selected.

Improper Joints

In many tests, however, the breaking stress f is much smaller than f_M, so much smaller that Equation 1 cannot account for the difference. This is observed when the joint is improper. Neither the adhesive nor the adherend breaks, but rupture occurs in a weak boundary layer. The small value of f in improper joints is associated with a visible effect; namely, one of the two adherends (or parts of each) appears clean after the rupture. In proper joints, the amounts of the adhesive remaining on the two fracture surfaces often have similar magnitudes.

Weak boundary layers can originate in various manners. A familiar example is offered by oily metals. When the adhesive does not displace or dissolve the oil, the latter remains between the metal and the solid adhesive and, when an external disruptive force is applied, the break occurs in the weakest material, that is, in the oil film. A weak material can also concentrate along the interface by diffusion from the adhesive, or can form as a result of a chemical reaction between adherend and adhesive, etc. Moreover, a proper joint may become improper in use, because of an unfavorable environment. For instance, the moisture of the air may promote a chemical reaction of the above-mentioned type.

Although there are about as many kinds of weak boundary layers as there are kinds of dirt, in every single instance it should be possible to detect the culprit and, consequently, to devise ways to improve the joint.

ABSENCE OF INTERFACIAL SEPARATION

The description of the rupture mechanism, as given in the preceding section, implies that a separation between the adherend and the adhesive, exactly along the interface, does not occur. Consequently, the forces of molecular adhesion across this interface do not determine the experimental strength of adhesive joints.

In many joints, true interfacial separation is impossible, because no interface exists. This is true whenever mixing between adherend and adhesive takes place. For instance, when two pieces of copper are soldered together, there is no sharp boundary between copper and solder because these two metals are mutually soluble and also form intermetallic compounds. Similar mixing may be expected when two silicate surfaces are joined by means of another silicate.

When a true interface exists (as far as we can judge), e.g., when two glass plates or two quartz grains are glued together with a hydrocarbon, such as polyethylene, then interfacial rupture is not strictly impossible, but is highly improbable. A reasonable estimate of this improbability is that in only one out of 100,000 joints will an interfacial separation about 10 atoms long occur by chance. For all practical purposes, such a separation does not need to be considered.

To understand the reason for this improbability, we should remember that the boundary between adherend and adhesive is a highly complicated surface having innumerable hills and valleys. The probability of a process continuing along this predetermined surface is as small as that of the fracture in a solid forming a bas-relief portrait. (1)

WHAT TO DO ABOUT POOR SEALANT PERFORMANCE

If a sealant does not perform well, a suitable way of detecting the reason, and finally finding a remedy for the poor performance, may comprise the following stages.

Find out whether the unsatisfactory sealant is or is not a good adhesive. If it is, the special requirements mentioned earlier in this paper have not been met. If it is not, then the problem to solve is whether it gives (in the combination in which we are interested) a proper or an improper joint. If the joint is proper, the cohesion ξ may be too small, or any of the values α, β and s may be too big. If the joint is improper, the cause of the weak boundary layer must be ascertained.

Obviously, a final answer is not likely to emerge within a day or two, but the guidance afforded by the correct theory is still better than no guidance at all or, even worse, the deceptive lead of a wrong hypothesis.

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Geometry of Simple Joint Seals Under Strain

By Egons Tons, Massachusetts Institute of Technology

Abstract: This paper correlates mathematically and by experiment the effects of joint width, sealed depth, and joint expansion on strains in joint seals. A theory of joint seal behavior is discussed and verified by laboratory tests. Major conclusions are: 1. If a rubbery, solid type of sealant is placed in a rectangular joint and subjected to strain (expansion), the curve-in surface follows a parabolic line; 2. Maximum strains in the sealant can be calculated by using parabolic equations and relationships; 3. For like conditions, the greater the minimum width of the joint, the less the sealant will be strained for the same percent of joint opening; 4. The shallower the joint is sealed, the less the sealant will be strained when the joint opens.

A JOINT IN A BUILDING undergoes continued changes in width due to temperature, moisture, and other fluctuations within the surrounding material. When such a joint is filled with a sealing compound, strains, and stresses caused by every opening or closing movement must develop, both within the sealant and along the bond interfaces. The mass of sealant in the joint can be pictured as a sort of bridge, spanning the gap between two slabs. Just as we try to design a bridge before it is built by using known quantities and methods, we should attempt to design a seal before it is placed in the joint.

The purpose of this study was to correlate mathematically and by experiment the effects of: 1. joint width; 2. sealed depth; and 3. joint expansion on strains in joint sealants.

THE THEORY OF JOINT SEAL BEHAVIOR

Basic Assumptions

The theory presented in this paper is based on calculations of maximum strain in the sealant because of joint width variations. The following assumptions (see Figure 1, page 50) were made to facilitate the analysis:

TONS, EGONS. Assistant Professor of Materials, Department of Civil Engineering, Massachusetts Institute of Technology; member, Association of Asphalt Paving Technologists, American Railway Engineering Association, ASTM, Highway Research Board.

1. The joint cross-section is rectangular.
2. The sealant is a rubbery solid which cannot change in volume, but instead changes its shape when the joint varies in width. The majority of sealing compounds currently used fall closely within this group. They show little if any change in volume when extended or compressed.
3. The curved-in top and bottom surfaces of the sealant resulting from joint expansion are parabolic in shape. This assumption is based both on observations of joints in the field and measurements in laboratory bond-ductility tests. These show that the curve-in line corresponds quite closely to a parabola for a wide range of sealed widths and expansions. (This is discussed further on in this paper.)
4. The sealant curves in equally from the two nonadhering sides of the joint. In some cases the back or bottom of the joint contains foreign matter which prevents adhesion. As will be seen in later calculations, there is a definite advantage in having the sealant curve in from two sides. In order to insure this, as well as to control the depth of seal, appropriate fillers or bond-breaking materials can be used as a backing for the joint.
5. The joint is originally sealed while at minimum width.
6. The strain in the sealant along the parabolic curve-in line is uniformly distributed. According to observations in laboratory tests, this assumption holds reasonably true for a wide range of joints at various stages of expansion, as is discussed later in this paper.

Symbols Used in This Paper

Most of the symbols used in this paper are shown in Figure 1. In order to provide a complete list, all of them are summarized below:

W_{min} - minimum joint width

W_x - joint width at any extension

W_{max} - maximum joint width

ΔW - linear expansion or change in joint width, in percent $\frac{W_x - W_{min}}{W_{min}} \times 100$

D_{min} - minimum depth of seal

D_x - depth of sealant in the joint

D_{max} - maximum depth of seal

H - maximum depth of the parabolic curve-in line

L - length of the parabolic arc (line ACB in Figure 1)

S_{max} - maximum strain in the sealant along the parabolic curve-in line, in percent $\frac{L - W_{min}}{W_{min}} \times 100$

A_s - cross-sectional area of the sealant

A_p - area enclosed by parabola (ABC in Figure 1)

Minimum Joint Width and Strains in the Sealant

For like conditions, the wider the joint at its minimum width, the less the sealant will be strained.

The amount of strain in a common, rubbery, solid type of sealant is not directly proportional to joint expansion, because the exposed surfaces curve down in the joint and do not stretch in a straight line (see Figure 1). Furthermore, the narrower the joint, the more severe the strains for any given percent of joint expansion (see Figure 2). If a narrow joint expands as much as a wider joint, remarkable strain differences can result (see Figure 3).

The Influence of Sealed Depth

While the effect of joint width upon the performance of a sealant has been recognized for a long time, the equally important depth or thickness of seal has, on the whole, been ignored. In fact, it is sometimes assumed that the deeper a joint is sealed the better. Theoretical calculations indicate the opposite is true, i.e., the shallower the seal, the less "curve-in" and the smaller the strains in the sealant (see Figure 4). This appears to be confirmed by our laboratory tests.

Procedure of Strain Computations

Figure 1 shows the shape of the sealant cross-section before and after extension. If the joint width before expansion is W_{min} (minimum width), and after expansion becomes W_x, and the joint has been sealed to a depth D_x, the increase in the joint cross-sectional area is $(W_x - W_{min}) \times D_x$. Since the sealing material acts like a rubbery solid, and is not able to change its cross-sectional area A_s', the two parabolic areas A_p will be equal to this increase (see Figure 1), and the maximum curve-in value H can be calculated as follows:

$$2A_p = (W_x - W_{min})D_x$$

$$A_p = 1/2\,(W_x - W_{min})D_x$$

but $A_p - 2/3\,HW_x$ (equation for a parabolic area)

from which $H = 3/2\,\frac{A_p}{W_x}$

where H = the maximum curve-in distance

A_p = area of one of the parabolas (area ACB)

W_x = the width of the sealed joint after expansion

W_{min} = minimum joint width

Any cross-section of a sealant in a joint can be divided into numerous layers. If the width of the joint is increased, the outer layers which follow the parabolic curve will be stretched most (see Figure 5). The length of this outer skin can be computed by using the formula for the arc length of a parabola:

$$L = 1/2\sqrt{W_x^2 + 16H^2} + \frac{W_x^2}{8H}\,\log_e \frac{4H + \sqrt{W_x^2 + 16H^2}}{W_x}$$

where L = length of arc ACB (see Figure 1)

H = the maximum curve-in distance

W_x = the width of the sealed joint after extension

W_{min} = minimum joint width

Once the length of the curve-in line is known, the actual maximum strains in the surface of the sealant under various conditions can be calculated:

$$S_{max} = \frac{L - W_{min}}{W_{min}} \times 100$$

where S_{max} = maximum strain in the sealant, in percent

L = length of arc ACB (see Figure 1)

W_{min} = minimum joint width, also equal to minimum L

The calculated maximum strain S_{max} in the sealant under ideal conditions depends upon: (a) the minimum sealed joint width; (b) the amount of joint expansion; and (c) the depth of seal. The numerous and repetitious calculations to correlate these factors were done by an electronic computer, and the results were compiled in curve form.

Discussion of the Theoretical Curves

By this procedure, the maximum strains in the sealant can be computed for any combination of depth of seal, joint width, and joint expansion up to 200%;[1] nine sets of curves are included for illustration (see Figs. 6-14.). They show that strains in the sealant can be decreased either by increasing the minimum sealed joint width or by decreasing the depth of seal.

Figures 6 to 9 show the variation of maximum strain (S_{max}) occurring along the parabolic curve-in line at various joint openings for eight minimum joint widths (W_{min}) and four different seal depths (D_x). Thus, Figure 8 gives comparisons for joints which have all been sealed to a depth of 2 inches, indicating considerable difference in amount of strain. For example, a joint with a minimum width of 1 inch ($W_{min} = 1$) expanding 50%, or an additional 1/2 inch, will induce an 87% strain in the outside layer (skin) of the sealant ($S_{max} = 87$). If, similarly, a 1/4 inch joint ($W_{min} = 1/4$) opens 50%, or 1/8 inch, the maximum strain in the sealing compound would be about 432% ($S_{max} = 432$), which is nearly four times as much.

Figures 10 to 13 show the variation of maximum strains (S_{max}) in the sealant with change in joint width for eight sealed depths (D_x) and four minimum joint widths (W_{min}). For example, if in Figure 11 the maximum strains (S_{max}) in the sealant are compared for sealed depths of 1/2 inch and 2 inches at 50% expansion, the same 87% versus 432% strains are found, just as in the previous example.

Figure 14 presents the calculated curves in a compounded form, correlating W, W_{min}, D_x, and S_{max}. To get it, Figure 13 ($W_{min} = 1$) was expanded by adding curves for depths (D_x) up to 24 in. It was found that the depth of seal (D_x) can be obtained for any joint width (W_{min}) by multiplying the depth required for a 1 inch joint ($W_{min} = 1$) by the minimum width of the desired joint. For instance, if a 1/2 inch wide joint ($W_{min} = 1/2$) has to be sealed for an expansion of 60% ($\Delta W = 100$), the maximum depth of seal $D_x = 2.0 \times W_{min} = 2.0 \times 0.5 = 1$ in.

Figure 14 again indicates the influence of the sealed depth and width upon the strain in the sealant. The narrower the minimum joint width, the shallower the seal has to be to keep the same strain and expansion values. In other words, the lower the depth to width ratio (D_x/W_{min}) the more stretchable the sealant will be.

Another important practical observation can be made from this figure; i.e., the advantages of a better or more stretchable sealant will be small if the seal is deep. For instance, if a low extensibility sealant with $S_{max} = 50\%$ is placed in a 1/4 inch joint ($W_{min} = 1/4$) to a 2 inch depth ($D_x = 2$), it will take theoretically about 7.5% of joint expansion ($\Delta W = 7.5$) before it fails. The same joint poured with a sealant which has $S_{max} = 150\%$ will fail theoretically at 21% of joint expansion, that is, after an additional 13.5%. If everything is kept the same except for reducing the depth of seal to 1/2 inch ($D_x = 1/2$), the sealant of low extensibility would fail at 30% of joint expansion, and the better one at 93%. Thus, the additional expansion obtained by using the more stretchable sealant is 63%, or nearly five times as much as is the case with the deep joint.

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[1] Theoretically, the two parabolas (see Figure 1) intersect at 200% of joint expansion, no matter what joint width or depth is taken.

LABORATORY TESTS TO VERIFY THE THEORY AND CALCULATIONS

Test Outline

The parabolic curve-in surface was observed in numerous bond-ductility tests in the laboratory, using various sealing compounds. Additional tests were performed to obtain more accurate measurements to justify the assumptions discussed above.

The length of specimens used in the laboratory test series was six inches to minimize the effect of curve-in from the two ends of the test blocks. The opening between the blocks (W_{min}) as well as the depth of seal (D_x) were varied to check the different ranges of the theoretical curves in Figures 6 to 14. The maximum sealed depth in these tests was limited to 3 in.

Previous laboratory observations have indicated that the basic curve-in pattern (parabola) is similar at 80° F. and 0° F., if the same rubbery, solid type of sealant is strained between two blocks (joint). However, the total strain that can be applied before the seal fails is usually less in the cold test. The laboratory tests reported on in this paper were performed at 80° F.

In this test series, two sealing compounds were used -- a hot-poured rubber-asphalt and a cold-applied, two-component synthetic polymer.

The following measurements and observations were made:

1. The maximum curve-in distance H was measured at different percentages of extension (joint expansion) on each specimen, and compared with the calculated values (curve). This was taken as an indication of how closely the actual curve-in line approaches a parabola.
2. The uniformity of strains along the curve-in surfaces was checked by marking them and observing the strains between various points visually.
3. The amount of curve-in from the top and the bottom of the specimen was compared.
4. Cohesion and other failures were closely watched and recorded.

The test data on the H measurements are compiled in graphic form in Figures 15 to 22. A discussion of the test results follows.

Discussion of Laboratory Test Data

Figures 15 to 18 summarize the H readings obtained on specimens of hot-poured rubber-asphalt sealant of varying depth (D_x). The horizontal axis gives the simulated joint expansion, while the vertical axis denotes the calculated maximum curve-in values (H). The solid line represents the computed H curve for a certain depth of seal (D_x) on each Figure, with which the measurements obtained in the laboratory strain test are compared. The mathematical equation for the parabolic H curves in Figures 15 to 22 is:

$$H = 3/4\ D_x \left(1 - \frac{100}{W + 100}\right).$$

If the measured H values at different depths of seal (D_x) and various expansions (ΔW) satisfy this equation, the curve-in line has to approximate a parabola.

The hot-poured rubber-asphalt specimens were strained to the maximum theoretical limit, which is 200%. The sealant in the 1/2 inch deep specimens followed the calculated H value curve very well (see Figure 15). It did not break at 200% extension, but continued to stretch in a thin band without showing any signs of failure. When the depth of seal was increased to 1 inch (see Figure 16), the narrow 1/8 inch specimens showed a marked deviation at about 75% of expansion, with some visible indications of separations within the sealant. When the sealed depth of 2 inches was tested, a similar departure from the basic curve was noted for the 1/4 inch specimens, while 3/8 inch and 1/2 inch wide seals fell below the curve after about 100% expansion (see Figure 17). Finally, when the compound was tested in 3 inch deep specimens, only the 1 inch wide seal ($W_{min} = 1$) followed the curve closely (see Figure 18). Again, inside separations, and even openings in the outside surfaces of the sealant, were registered as soon as the H measurements dropped about 10% below those calculated.

The maximum curve-in value measurements for the cold-applied rubber polymer are summarized in Figures 19 to 22. The force required to pull this type of seal apart was considerably higher than that necessary for the rubber-asphalt compound. Due to some limitations in the strain apparatus, the specimens in these series were extended only by 100%. The trend of the actual measurements was very similar to the previously discussed rubber-asphalt results. Even the separations and openings in the sealant, when the H values started to drop below the theoretical curve, were of the same nature.

The results obtained with the two sealants indicate that the H measurements taken in the laboratory were comparable to the calculated ones, which in turn means that the curve-in line of the surface of the sealant closely approached a parabola. The apparent deviations from the parabolic curvature occurred:

1. When the sealant was placed to a shallow depth, and unreasonably large strains were applied (around 200% extension). (See Figure 23.)

2. When the seal lost its homogeneity and started to form air spaces inside (see Figure 24). This is much more likely to happen when a narrow and deeply sealed joint expands. Observations so far indicate that, in case of homogeneous materials such as those used in the tests, and under the conditions described, such air spaces form when the tangent to the parabola has an angle of 15° to 25° to the vertical (see Figure 24). Apparently this phenomenon is related to the magnitude of the shear and tension forces in the sealant along the joint walls.

Visual observations of the distribution on the strain along the curve-in surface of the sealant indicated that it is uniform at low percentages of extension, but tends to vary slightly when the strains get high and the material has sagged deep into the opening (joint). For all practical purposes, the assumption of a uniform strain along the surfaces of the sealant seems reasonable.

The amount of curve-in at the bottom of the specimen was also measured, and was found to average out identically with the one on the top.

EFFECT OF TYPE OF SEALING MATERIAL ON STRESS DEVELOPMENT

The desired engineering properties of a sealant in a joint have not been well defined. An ideally elastic material, subjected to tension as described in this paper, would follow closely the "parabolic rule," and resume its original shape when the joint width returned to the previous, as-sealed dimension. If the joint happens to be sealed during the warmest period of the year, it is likely that only tensional stresses will be induced in the sealant. The strain-stress pattern will be complex with the maximum occurring along the free interface "skin." The bond between the sealing material and the joint faces will be subjected to tension at the outset of the joint expansion, and will change to tension-shear combination with the increase in joint width (due to the parabolic neck-down). The maximum bond stress will occur at the edge of the joint (at point A, Figure 1). If an ideally elastic material is used, the stress in the sealant and along the bonded interfaces will increase with widening of the joint. Furthermore, this stress in many cases may be of a long duration (all through the cold season). Any imperfections in the bond due to workmanship or localized influence of environment can initiate a failure which will progress with time.

The other extreme could be a material exhibiting practically complete stress relaxation at the rates of strain encountered in a building joint. Assuming again the simple case of tension, the sealant may follow closely the "parabolic rule" while stretched, but the stress imposed on the bond at point A, Figure 1, and all along the sealant and joint wall interface, would be relatively small due to the plastic (permanent) adjustment exhibited by the material. Thus, by the use of an "ideally plastic" material, the prolonged high stress on the bond would be avoided. The main disadvantage, as compared to an ideally elastic material, would be the inability of the sealant to resume its previous shape when the joint closes to the original width, and the material is compressed (unless the joint itself can act as a mold, squeezing the sealant back into shape). In other words, only an elastic sealant will follow the "parabolic rule" during both extension and recovery; the "plastic" sealant may obey only during the extension phase.

Finally, it must be recognized that, under actual conditions, joints are not sealed when their width is at minimum. Thus, both extension-recovery and compression-recovery cycles are common in a joint seal in a building. The compressive cycle, however, does not induce much strain on the adhesive bonds along the joint sealant interface.

WHAT HAS BEEN LEARNED FROM THIS STUDY

The data compiled in this paper indicate that conventional joint sealants, especially when placed in narrow and/or deep joints, will be subjected to high strains under service conditions. These strains are often accompanied by considerable stress within the sealant and along the bond interface of the joint wall.

There may be several possibilities to improve joint-sealing materials and techniques. This would involve optimization of the joint size and shape, as well as the properties and physical dimensions of the sealant itself. From this limited study it is apparent that, in order to eliminate or diminish the "necking down" of the sealant in a joint, thin membrane or tape types of sealants may be beneficial. Also, a sealant which follows the volume changes of the joint without "necking down" would be valuable. Furthermore, it appears that a joint seal would be more reliable in service if, instead of being tensioned through most of its life, it could serve only under compression, without stress reversals. This would help to preserve bond contact between the sealant and the joint.

CONCLUSIONS

This paper outlines a procedure for estimating tension strains in a homogeneous, semi-solid sealant used for sealing joints in structures. The assumptions and theoretical calculations have been verified by laboratory test. The major conclusions from this study are:

1. Laboratory tests indicate that, if a rubbery, solid type of sealant is placed in a rectangular joint and subjected to strain (expansion), the curve-in surface closely follows a parabolic line.

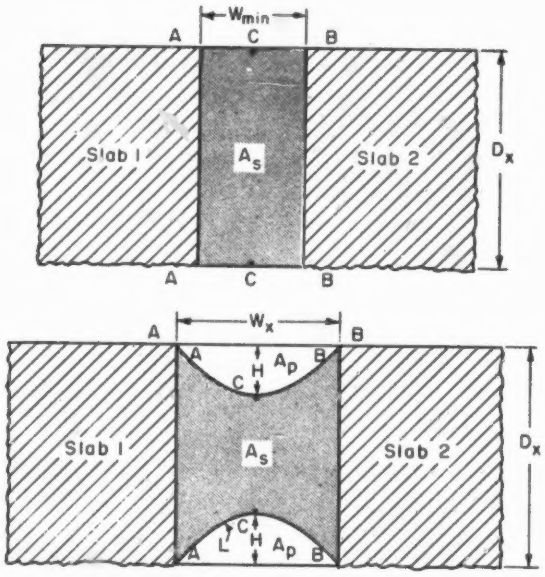
2. Maximum strains in the sealant can be calculated by using parabolic equations and relationships.
3. The calculations show that for like conditions, the greater the minimum width of the joint, the less the sealant will be strained for the same percent of joint opening.
4. The shallower the joint is sealed, the less the sealant will be strained when the joint opens, other conditions being the same.

SUGGESTIONS

The most important suggestions derived from this study are as follows:

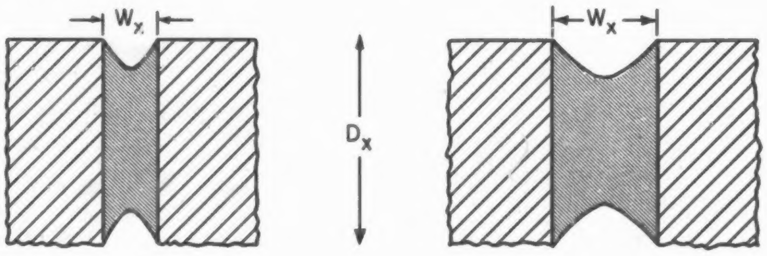
1. More effort should be placed on development of sealants with high width to depth ratio (membrane type), or sealants which can change volume as the joint opens (no "neck-down").
2. More emphasis should be placed on development of elastic compression type sealants which can change volume with variations in joint width.

(See Figures 1-25, pages 50-61)



W_{min} = minimum joint width
W_x = joint width of any extension
D_x = depth of sealant in the joint
H = maximum depth of parabolic curve-in line
L = length of parabolic arc (line ACB)
A_s = cross-sectional area of sealant
A_p = area of parabola ABC
ΔW = amount of joint expansion (%)
S_{max} = amount of maximum strain in sealant (%)

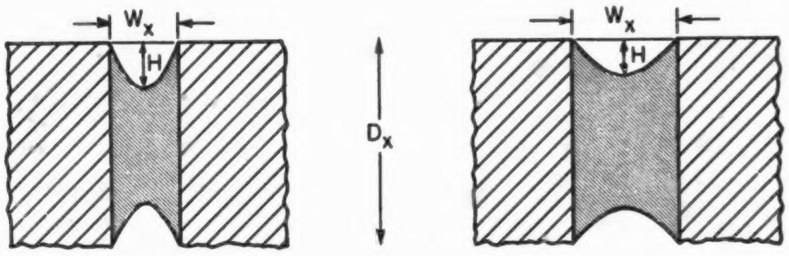
Figure 1 -- Top: Sealed joint at minimum width. Bottom: Sealed joint after expansion.



W_{min} = 1/4 in.
W_x = 3/8 in.
D_x = 1-1/2 in.
ΔW = 50%
S_{max} = 248%
(from Fig. 11)

W_{min} = 1/2 in.
W_x = 3/4 in.
D_x = 1-1/2 in.
ΔW = 50%
S_{max} = 120%
(from Fig. 12)

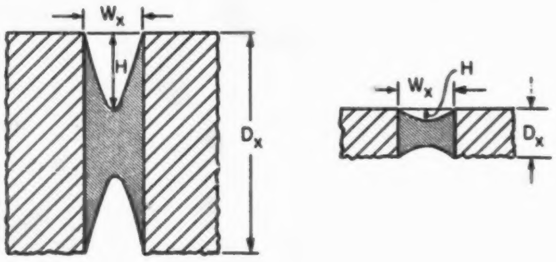
Figure 2 -- Comparison of maximum strains(S_{max}) in the sealant for two joint widths (W_{min}) with 50% expansion (ΔW = 50).



W_{min} = 1/4 in.
W_x = 1/2 in.
D_x = 1-1/2 in.
ΔW = 100%
H = 0.575 in.
W_x-W_{min} = 1/4 in.
S_{max} = 410%
(from Fig. 11)

W_{min} = 1/2 in.
W_x = 3/4 in.
D_x = 1-1/2 in.
ΔW = 50%
H = 0.375 in.
W_x-W_{min} = 1/4 in.
S_{max} = 120%
(from Fig. 12)

Figure 3 -- Comparison of maximum strains (S_{max}) in the sealant for two joint widths (W_{min}) with 1/4 inch expansion.



W_{min} = 1/4 in.
W_x = 1/2 in.
ΔW = 100%
H = 0.75 in.
D_x = 2 in.
S_{max} = 550% (calculated)

W_{min} = 1/4 in.
W_x = 1/2 in.
ΔW = 100%
H = 0.19 in.
D_x = 1/2 in.
S_{max} = 160% (from Fig. 11)

Figure 4 -- Comparison of maximum strains (S_{max}) for 2 inch deep and 1/2 inch deep seals (D_x = 2 in. and D_x = 1/2 in.)

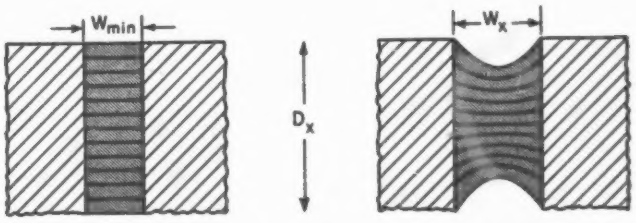


Figure 5 -- Visual strain comparison in the sealant at different levels for W_{min} = 1/2 inch and W_x = 3/4 inch.

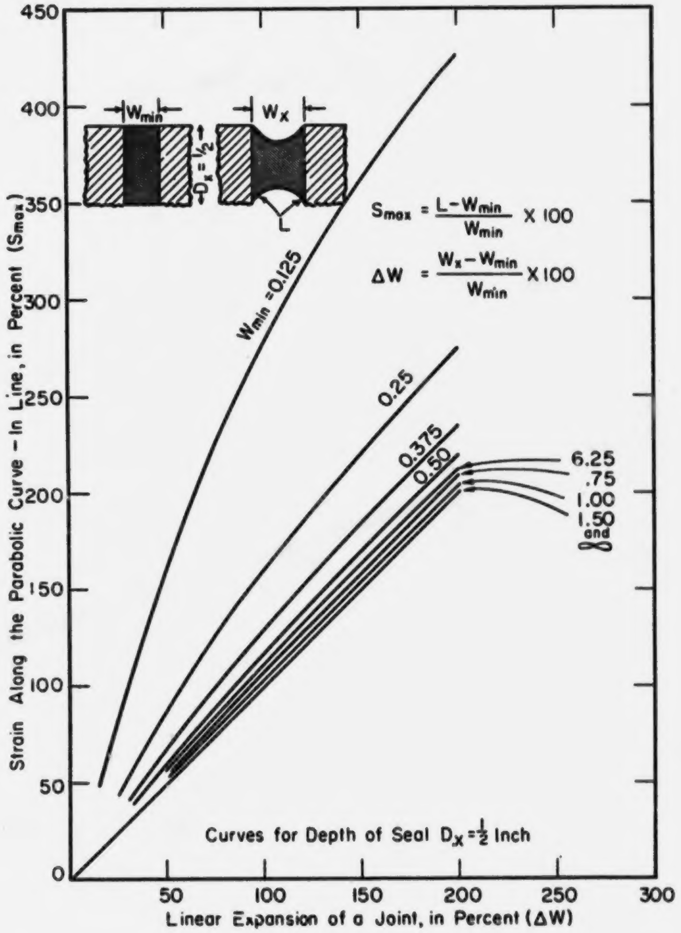


Figure 6 -- Comparison of strains in the sealant for various joint widths and 1/2 inch depth.

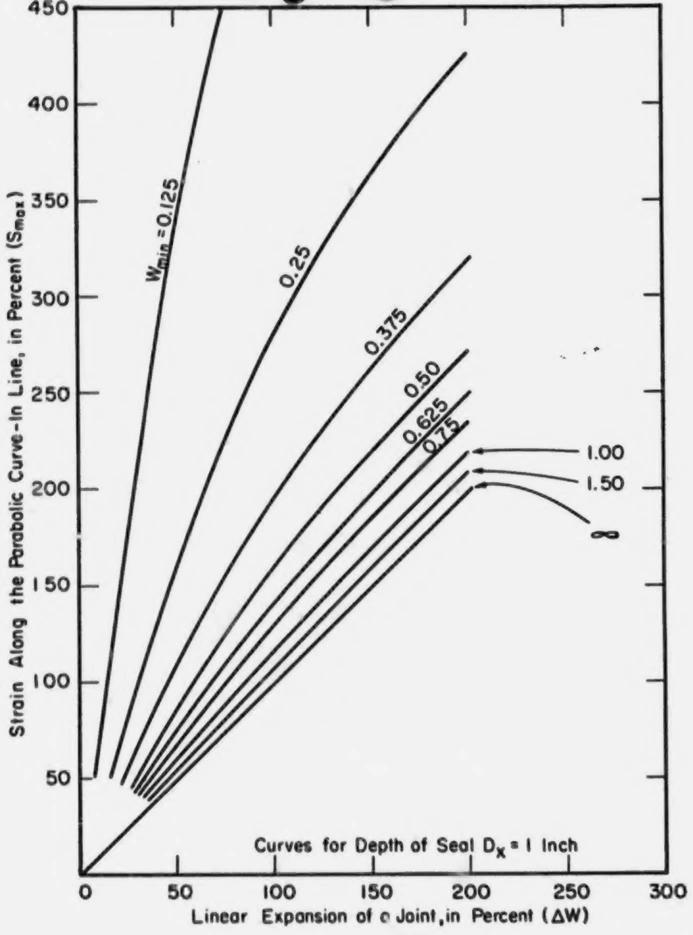


Figure 7 -- Comparison of strains in the sealant for various joint widths and 1 inch depth.

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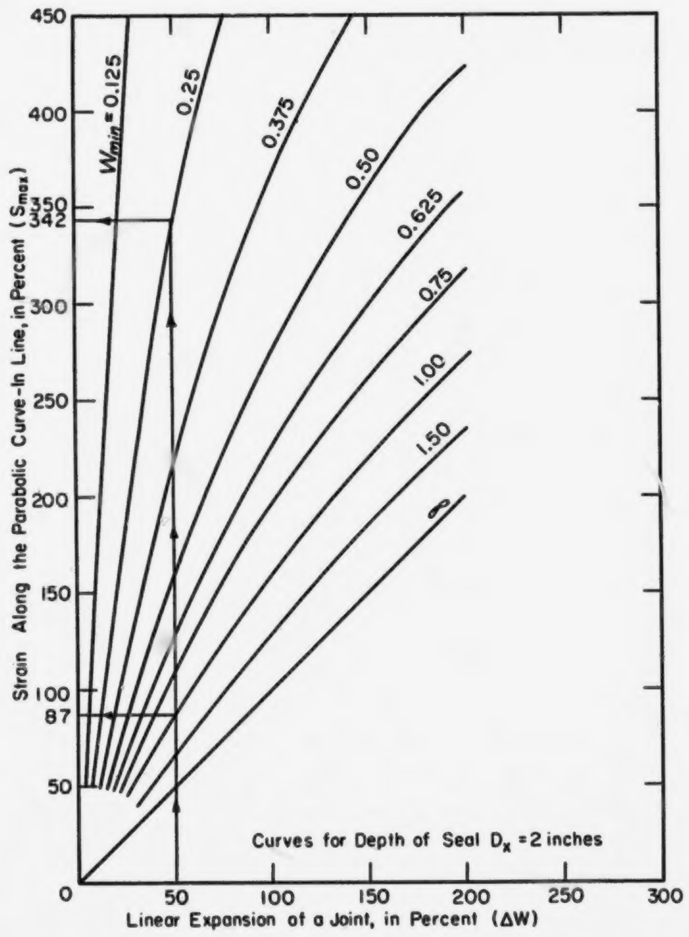

Figure 8 -- Comparison of strains in the sealant for various joint widths and 2 inch depth.

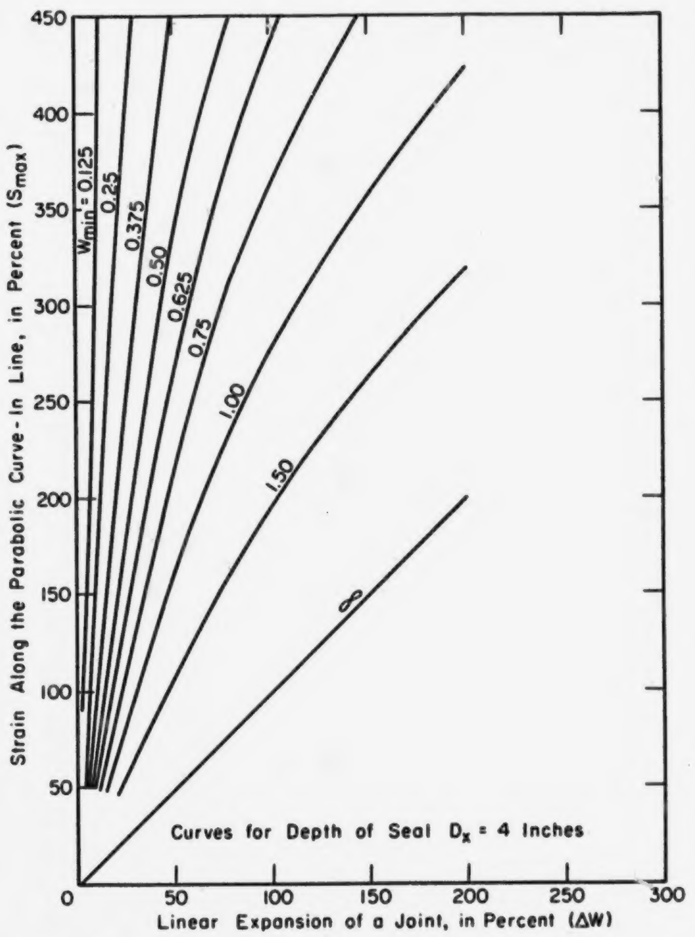

Figure 9 -- Comparison of strains in the sealant for various joint widths and 4 inch depth.

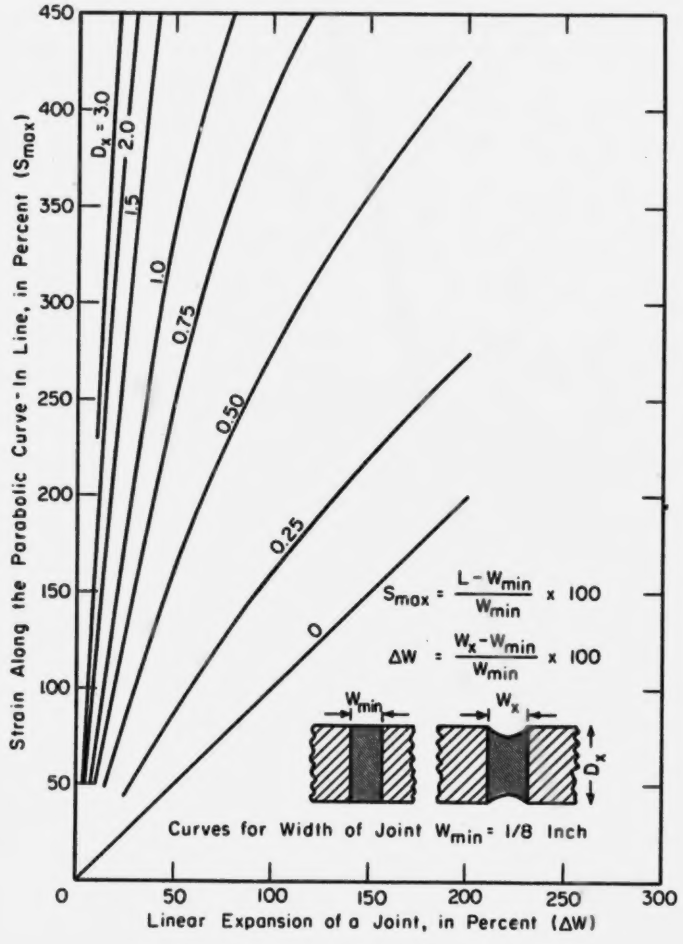

Figure 10 -- Comparison of strains in the sealant for various depths of seal and 1/8 inch width.

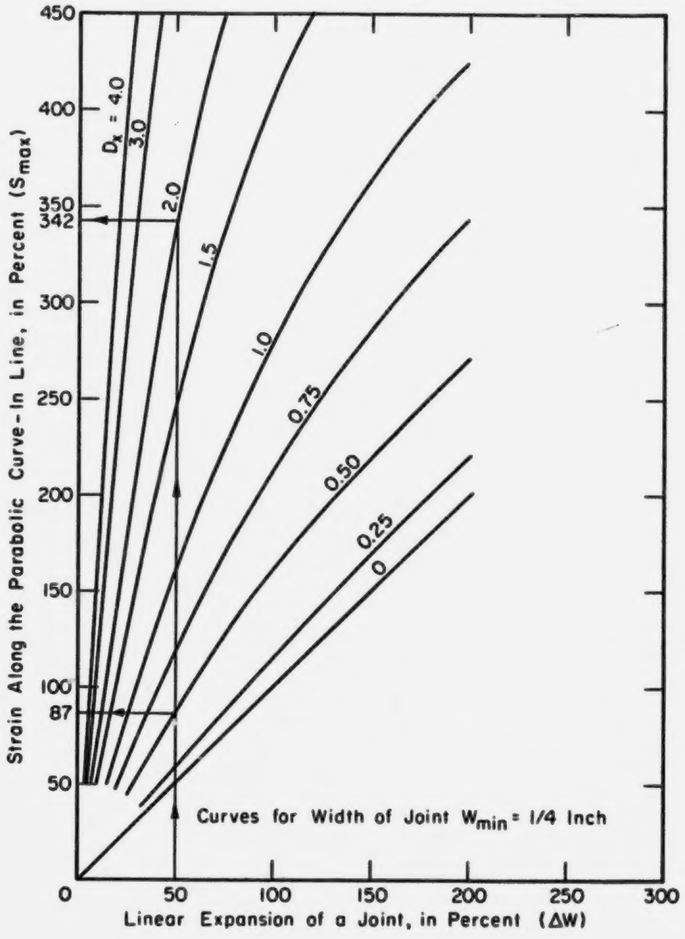

Figure 11 -- Comparison of strains in the sealant for various depths of seal and 1/4 inch width.

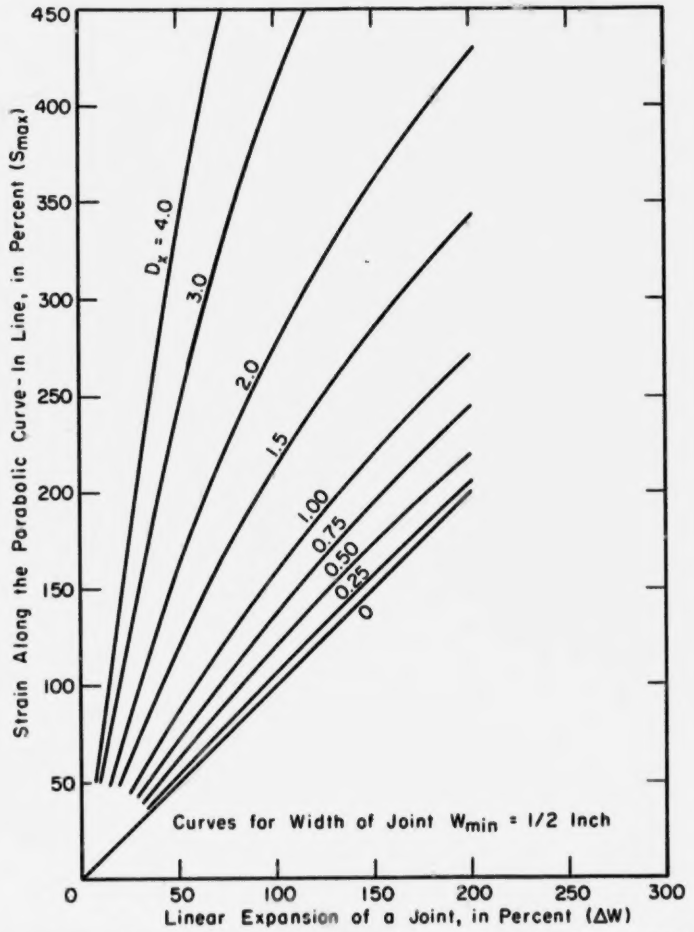

Figure 12 -- Comparison of strains in the sealant for various depths of seal and 1/2 inch width.

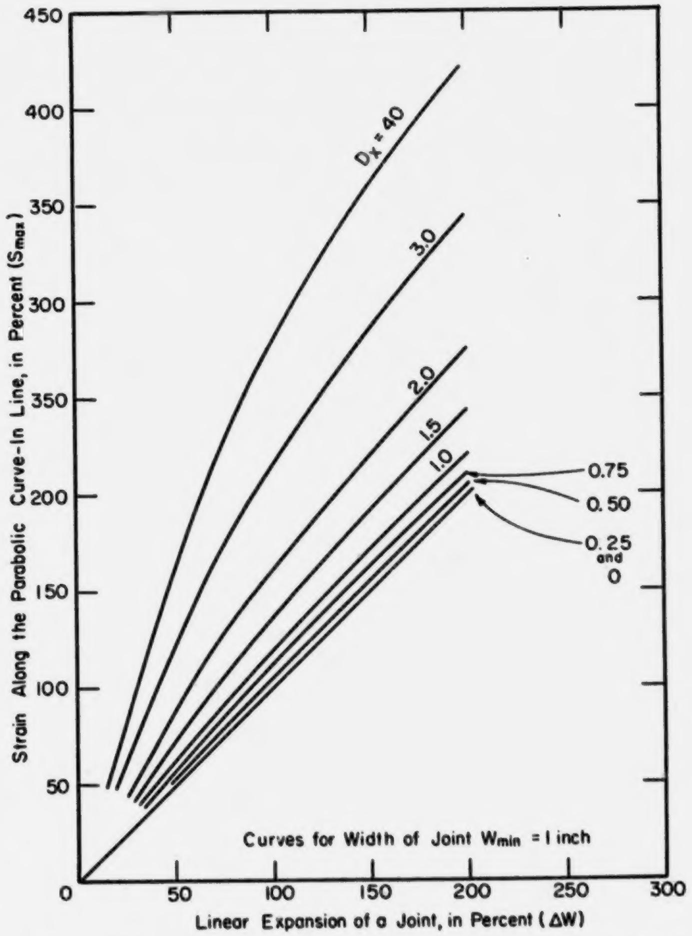

Figure 13 -- Comparison of strains in the sealant for various depths of seal and 1 inch width.

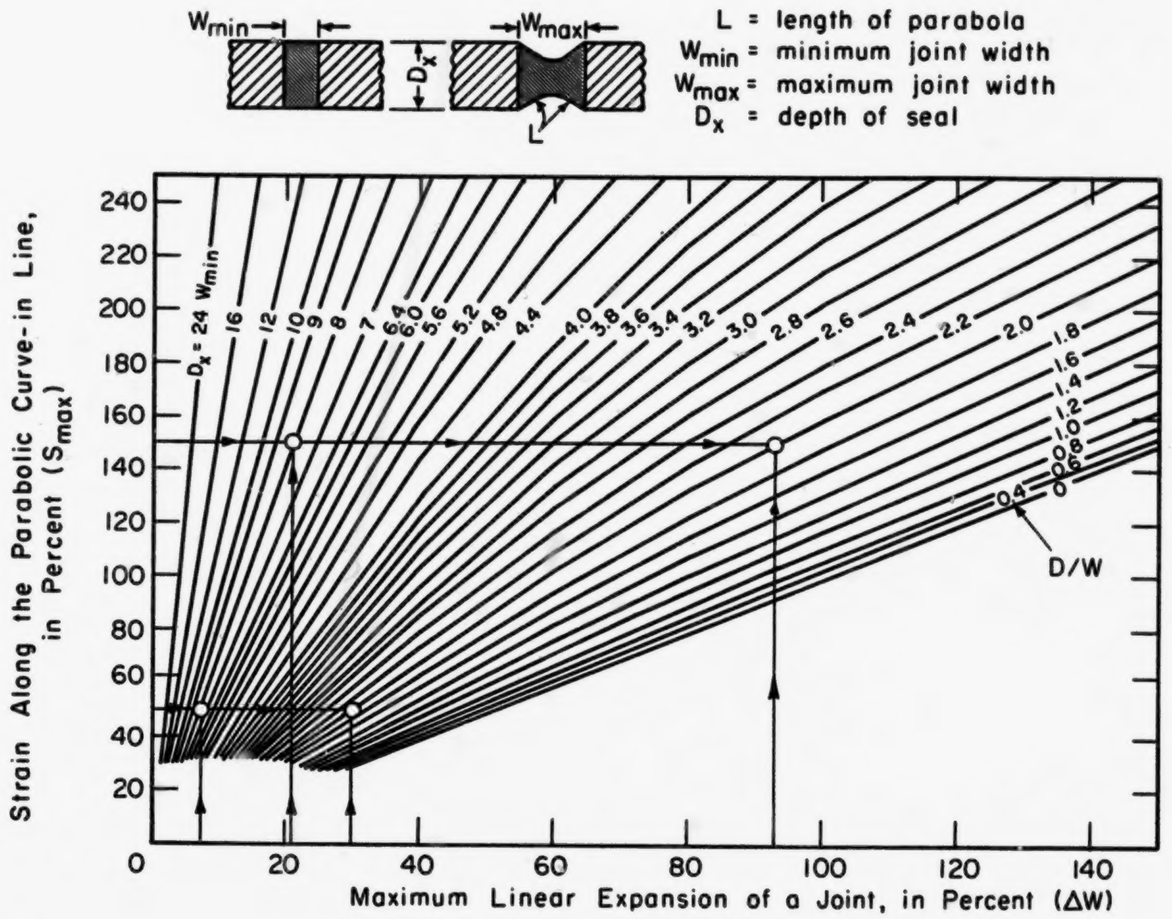

Figure 14 -- Relationship between ΔW, W_{min}, D_x, and S_{max} in a sealed joint.

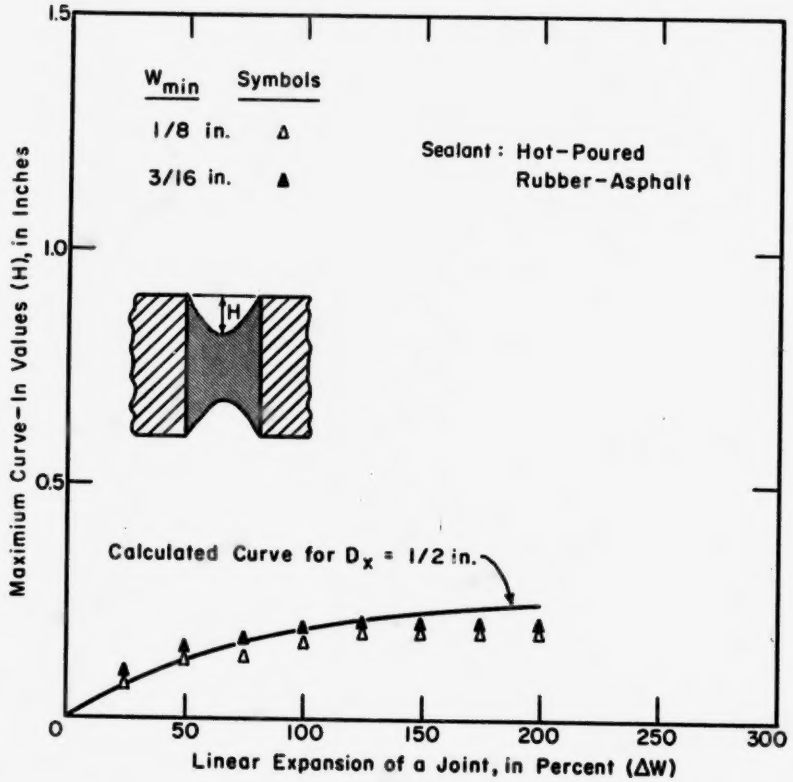

Figure 15 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_X = 1/2 inch and varied joint widths (W_{min}). Sealant is a hot-poured rubber asphalt.

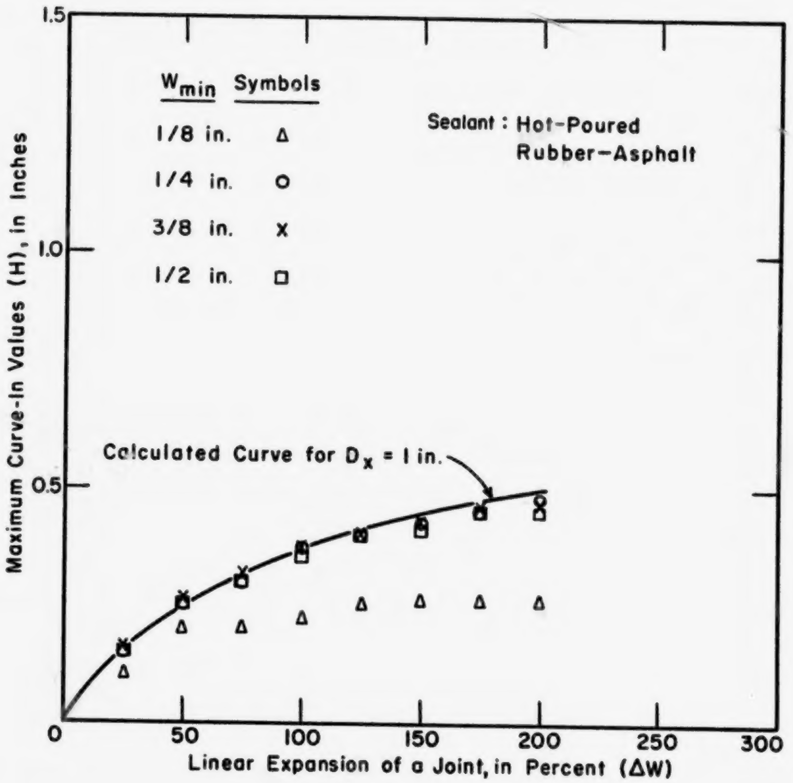

Figure 16 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_X = 1 inch and varied joint widths (W_{min}). Sealant is a hot-poured rubber asphalt.

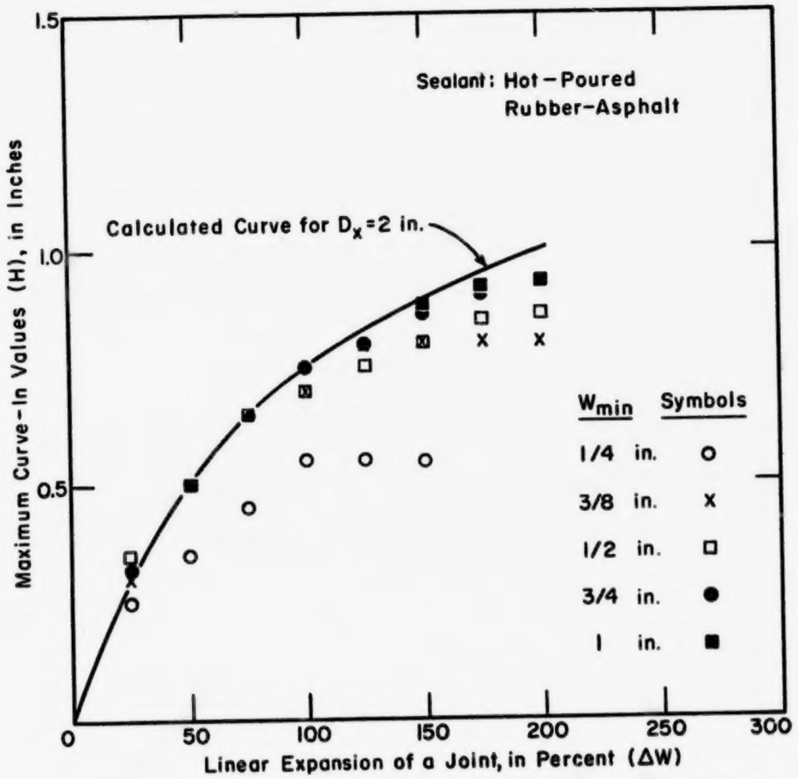

Figure 17 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_X = 2 inches and varied joint widths (W_{min}). Sealant is a hot-poured rubber asphalt.

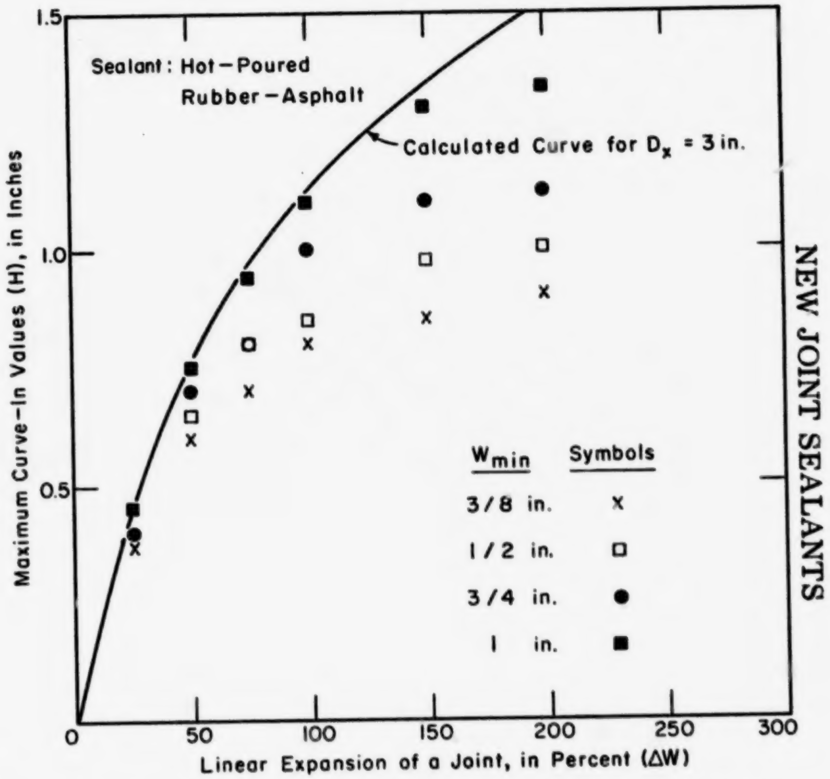

Figure 18 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_X = 3 inches and varied joint widths (W_{min}). Sealant is a hot-poured rubber asphalt.

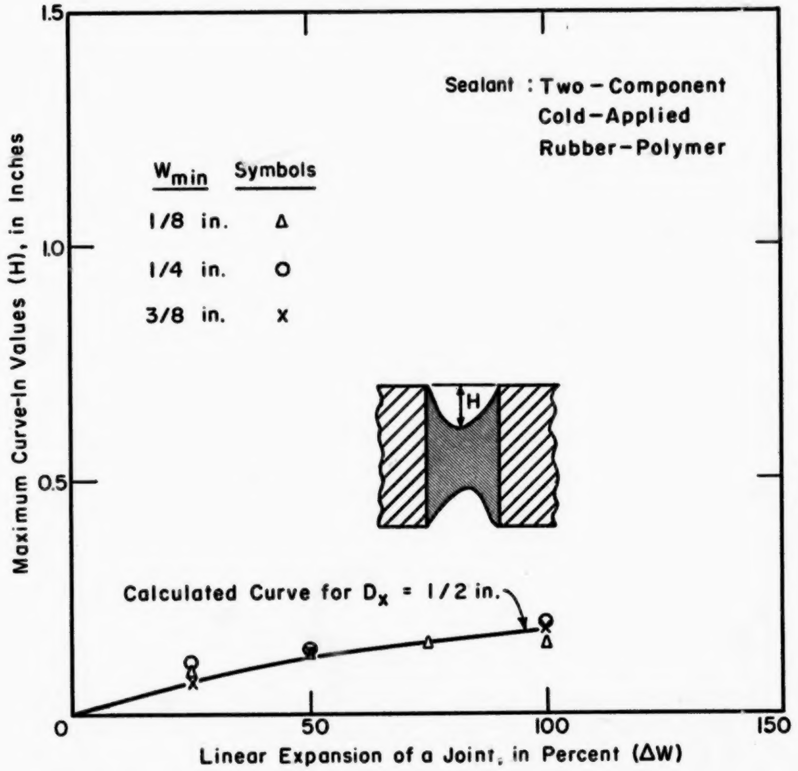

Figure 19 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_x = 1/2 inch and varied joint widths (W_{min}). Sealant is a two-component cold-applied rubber polymer.

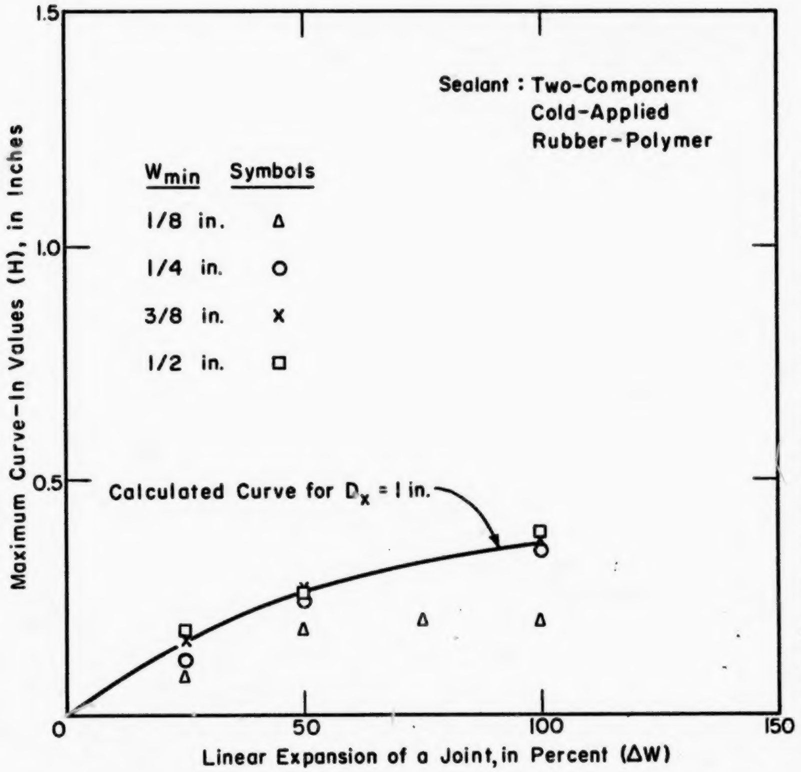

Figure 20 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_x = 1 inch and varied joint widths (W_{min}). Sealant is a two-component cold-applied rubber polymer.

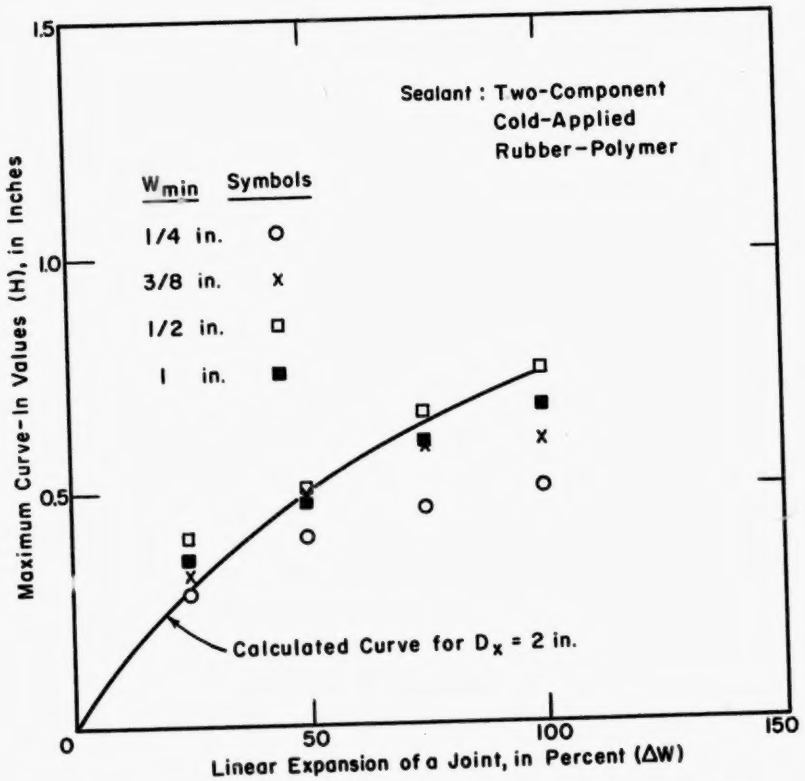

Figure 21 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_x = 2 inches and varied joint widths (W_{min}). Sealant is a two-component cold-applied rubber polymer.

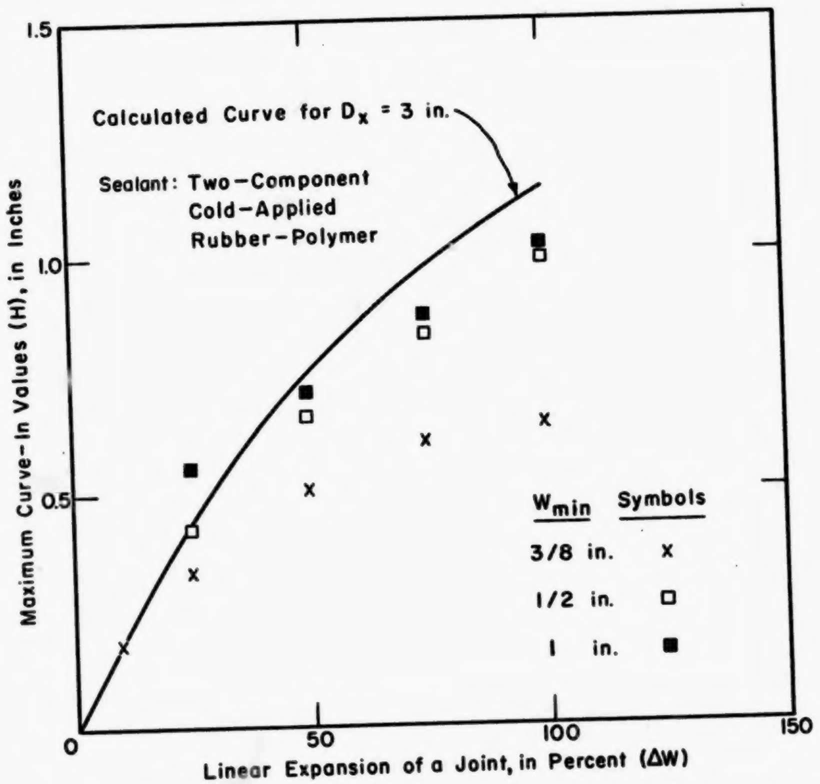

Figure 22 -- Comparison of calculated curve-in values (H) with those measured in the laboratory for D_x = 3 inches and varied joint widths (W_{min}). Sealant is a two-component cold-applied rubber polymer.

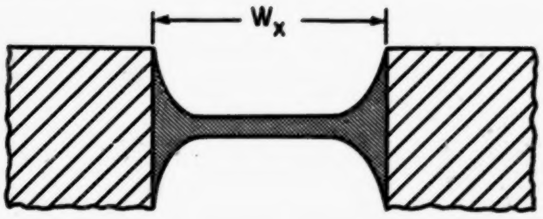

Figure 23 -- At joint expansions approaching 200%, a sealant in a shallow joint might not follow a parabolic curve-in line.

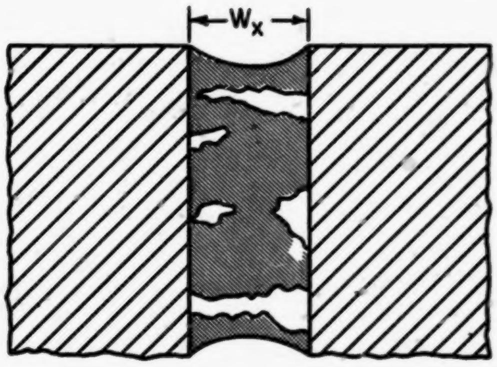

Figure 24 -- In most cases, if a sealant does not follow the parabolic curve-in line, an internal (cohesion) rupture is imminent.

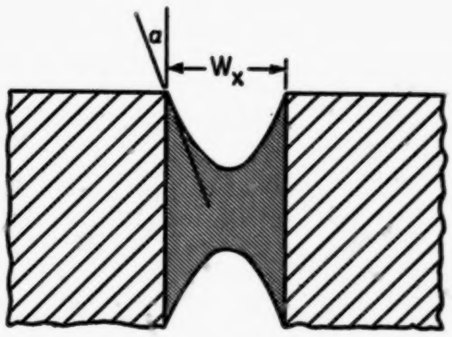

Figure 25 -- The tangent angle α was found to be 15° to 25° at the time of most failures of deep seals.

Joint Sealant Specifications from a Manufacturer's Viewpoint

By Joseph S. Amstock, Products Research Company

Abstract: A joint sealant specification is valuable for defining a high quality product for the consumer, but it does not prevent poor application, poor workmanship, or misuse. The joint sealant specification should be written in terms of existing high quality materials and realistic requirements, and should be tested under conditions approximating actual use and allowing reproducible results. Tests described are application life, cure time and hardness, adhesion in tension and ultimate elongation, ultraviolet resistance, and staining. Any proposed joint sealant specification should be submitted to the manufacturer prior to release.

TO THE AVERAGE PERSON, THE TERM "joint sealant specifications" means very little, and few people have any concept of what they are, how they are used, or the complex amount of information and research required to write such a document.

Writing a joint sealant specification for the building and construction industry is always an exacting task. A good joint sealant specification does not come easy; it takes time, knowledge of materials, knowledge of areas of application, and an extended effort by many people. Present-day construction has created an urgent need for joint sealant specifications. As a result of this need, the current American Standards Association Specification, ASA 116.1, represents the combined efforts of two industry groups to develop a material standard for a type of joint-sealing compound. This specification has found wide acceptance in the construction industry throughout the United States.

On February 26, 1959, the Building Trade Specification Committee (composed of polysulfide sealant manufacturers) and the Rubber and Plastic Adhesives and Sealants Manufacturers Council met with the American Standards Association in Pittsburgh. The specification had been submitted by the Building Trade Specification Committee, and a motion was made by the Rubber and Plastic Adhesives and Sealants Manufacturers to amend it. The final draft was prepared, reviewed and subjected to balloting in October 1959.

AMSTOCK, JOSEPH S. Chief Chemist, Eastern Division, Products Research Company; member, American Chemical Society, ASTM, BRI, Society of the Plastics Industry. Acknowledgment is made to Don Corkill, Manager, Engineering Service Department, Products Research Company, for his assistance in preparing this paper.

General acceptance was indicated by this canvas, and final approval as an American Standard was given in July 1960.

PURPOSE OF SPECIFICATION

The scope and purpose of this engineering document is to transmit technically the requirements pertaining to the quality and/or performance of a joint sealant. To accomplish this, the writer of the specification must understand the products and the data he intends to transmit. Since this document is in the realm of a highly specialized treatise, it is up to the sealant manufacturer to exercise extraordinary care and caution to set forth only those data which can be substantiated for their accuracy and reproducibility.

With the present-day trend in new construction, toward more and more sealing of curtain walls, expansion and contraction joints in bridge decks, joints in tilt-up construction, and many other types of joints, the problem is to provide watertight and airtight seals.

Before proceeding further, an important point regarding material specifications should be brought to the attention of every potential user of such documents. As stated before, the basic purpose of a material specification is to define for the consumer a high quality product. However, regardless of the high quality of the product, and regardless of how far the material properties exceed the specified requirements, the joint sealant specification does not protect the ultimate purchaser, that is, the building owner, from faulty application of the joint sealant, due to improper surface preparation, improper mixing, or a poor choice of sealants for the particular application. In other words, a material specification is not a job warranty to the ultimate purchaser.

A specification may be very broad, covering several materials, or it may be limited to one specific material, depending on the desired scope and intended areas of usage to be covered. For instance, a specification may describe various individual classes of materials, where each class has a specific requirement based on the intended use. Such specific requirements could be stain resistance, ultraviolet ray resistance, hardness, etc. Thus, a material in a nonstaining classification would be specified for applications where this requirement was of particular significance. A nonstaining material might not have as good ultraviolet ray resistance as another material in the UV-resistance class. Or, it may be desired that the material have both stain and ultraviolet ray resistance, and also be classified by hardness. In this case, the primary difference between the specification materials would be that one class of material is harder or softer, and still meet the other requirements.

Further subdivision of a specification could be by types. It may be desired that all classes of material meeting the specification be of the self-leveling or pourable type, and a thixotropic or nonsag type.

All of this serves to illustrate what was meant when it was stated that a material specification takes time, knowledge of materials, knowledge of areas of application, and an extended effort by many people. This would vary, of course, as related to the complicated specification with three or four subdivisions, or the relatively simple specification covering only one material for one specific use.

Regardless of the complexity or simplicity of a joint sealant specification, there are some basic points common to both.

1. The requirements should be pertinent to the proposed applications within the scope of the specification, or the areas of intended use of the material.
2. The requirements should be realistic. They should be fairly difficult to meet, so that only high quality materials qualify under the specification, yet not so difficult that higher quality and consequently higher priced materials are required than the intended use warrants.
3. The specification should be written in terms of existing high quality materials, since it would be worthless and a waste of time if there were no products available which could meet it.
4. Test methods included should be of the type which will approximate as closely as possible actual use conditions so that the test results are significant. Realistic requirements have no meaning, unless appropriate test methods are used.
5. Test methods should allow for reproducible results, regardless of who runs the tests. If the same results cannot be obtained within testing tolerances by the same tester, or by two different testers, the test methods are not correctly specified.

TESTS AND TEST METHODS

The order in which these tests are discussed does not mean that one test is more important than another. All are valuable, but a specific test may mean more to one architect or engineer, depending on the type of design or structure involved.

Also, it should be explained why some tests are run under conditions which are not normally encountered in the field, e.g., 75° ± 2° F, and 50 ± 5% relative humidity. Such perfect weather is hard to find, and joint sealants are used nationwide under almost every condition except this one. However, the reason is simply for uniformity of testing, regardless of where, when, or by whom. Thus, since "standard conditions" must be used for some tests, it is necessary for the specification writer to use his knowledge of materials to set requirements at such values that the material can be used satisfactorily from Alaska to Florida and from Maine to Hawaii.

Of course, specific tests can also be placed in the specification to cover extreme conditions. For instance, flexibility at -40° F to test the cracking resistance of the material in cold weather, or heat-aging at 160° F to test softening or melting resistance in summer heat.

Application Life

The application life of a sealant is the length of time after mixing that is available for the workman to apply the material. This usually applies to multiple-component sealants. A practical application life for sealants in the building industry is three hours, although this value can be varied depending upon construction conditions. A simple test method for the determination of application life, which approximates actual application with a calking gun, is the minimum extrusion rate of the material at a specified pressure and for a specified time.

Cure Time and Hardness

The common definition of cure time is the length of time required for the material to cure. This, naturally, applies only to curing materials, and not to mastics which are to remain in an uncured state. However, in a material specification, it is necessary to go one step further and describe what state of cure is required. It is possible to have the cure time based on hardness, and this value may or may not be the ultimate hardness. Also, a material may be considered cured by the hardness method, and still not be sufficiently cured to provide optimum adhesion, or some other desired characteristic.

Usually, cure time is defined as the time required for a material to reach a specified hardness, because this is the simplest and most practical method. The specific hardness used depends on what the ultimate hardness will be; how the hardness value correlates to other properties, such as adhesion, elongation or water resistance; and the importance of hardness to that particular area of usage covered by the specification.

Hardness is considered a measure of resistance to indentation, i.e., the harder the material the more resistant it is to indentation. Hardness values are determined by the use of a Rex or Shore A durometer gauge.

We have found from experience that the best range of hardness for joint sealants, with other appropriate properties taken into consideration, is 15 to 20 Shore A hardness points.

Adhesion in Tension and Ultimate Elongation

Extreme movement in structures resulting from temperature changes, high wind velocities and driving rain make it essential that joint sealants be compounded to withstand such environmental conditions, if they are to do an effective job of sealing the joints.

We have grouped adhesion in tension and ultimate elongation together because they are closely related in actual joint movement. As a joint opens, the joint sealant is stretched. Assuming that the joint opens to the destruction point of the sealant, how far the joint opens before failure, and whether the failure is cohesive or adhesive depend upon the ultimate elongation and tensile adhesion values of the material. If the adhesive strength is greater than the tensile strength of the material, the failure will be in cohesion, but if the adhesive strength is less than the tensile strength, then adhesion failure will result.

A method of testing these properties, which approximates actual joint movement, is to apply the material between two faces of test surface, such as masonry, metal or wood, in a typical joint configuration, e.g., 1/2 in. x 1/2 in. x 2 in. After the material has cured, the test surfaces can be pulled apart perpendicular to the joint face, simulating the opening of a joint. The distance the material stretches to failure and the force necessary to cause failure can then be recorded. Failure in adhesion or cohesion can also be determined thereby.

Adaptions can be made using the above-mentioned procedure to check the sealing material in various environments, such as immersion in water, heat-aging, temperature cycling, and low temperatures.

Ultraviolet Resistance

Sealants which are to be used for glass sealing and glazing should be specifically compounded to have maximum resistance to ultraviolet attack, because the action of ultraviolet rays can have a detrimental effect on joint sealing materials, causing them to discolor, lose resiliency, and finally lose adhesion.

It should be noted that the effect of sunlight on a sealant when not exposed through glass is completely different. In most cases, a chemical reaction occurs between the sealant and glass surface when exposed to ultraviolet through glass, and even more serious problems occur when this same material is immersed in water. Experience reveals an adhesion panel exposed to natural sunlight can fail even more rapidly than a laboratory sample exposed to ultraviolet and water immersion.

The same general testing procedure as described above for adhesion in tension testing can be used, except that one test surface should be aluminum, and the other water-white glass. These specimens can then be exposed to ultraviolet lamps followed by water immersion, or exposed to natural sunlight. After the desired length of time, the surfaces can be pulled apart to determine adhesion in tension and elongation values.

Staining

One of the most important and most necessary tests of a joint sealant is to determine its resistance to staining or discoloration.

A very brief and simple laboratory test for certain types of staining is to place the sealant in question on a white portland cement-lime mixture and keep the specimen in a high humidity. If there is a tendency to stain, a pink discoloration of the cement-mortar mixture will appear. A more extensive test has been developed by the National Bureau of Standards, which employs the use of a weatherometer and control samples. This procedure is outlined in Interim Federal Specification, TT-S-00227.

Miscellaneous Tests

There are other tests and requirements which can and should be included in a material specification for joint sealants. Tests for such properties as nonvolatile content, viscosity, and color stability are some of them. These tests may not appear to be as important as tests for adhesion, staining, etc., but they are important to the over-all quality of the material.

Quality Assurance

With all these tests in mind, the joint sealant manufacturer must then be able to assure the architect and calking contractor that his is a quality product, and make available to them his test facilities and technical services. Many architects and engineers require notarized and certified test reports. This should not pose a problem, since all sealants should be tested in their entirety against a given specification or by standard, accepted commercial practices.

It should be made clear that no specifications written around joint sealants can guarantee workmanship, or performance in questionable applications. They will, however, assure the applicator of a quality product, and of the competence of the manufacturer.

CURRENT SPECIFICATIONS

Several specifications are available dealing with joint-sealing materials. Some are based primarily on polysulfide liquid polymers; others on standard oil-base calks, asphalt and bitumastic types of sealants. Those more commonly used are:

American Standard Association Specification ASA 116.1
Interim Federal Specification TT-S-00227
New York Department of Public Works, Items 351 and 352X
State of Rhode Island, Item 4-4-2
Federal Specification TT-C-598
Federal Specification SS-S-200, a and b
Federal Specification SS-S-195

SUMMARY

In conclusion, let us summarize the most important points previously discussed.

1. A material specification is a valuable tool for the architect, applicator, and building owner for selecting a quality material. However, the material specification does not prevent poor application, workmanship, or misuse of the material.
2. A material specification should be written around existing high quality materials, and encompass realistic requirements and reproducible tests resembling the actual environment to be encountered as closely as possible. The test materials should be the same as those on which the sealing compound will be applied.
3. A material specification can only approximate actual service, and how close the approximation is depends greatly on the requirements, and particularly on the test methods.

One last point that should be mentioned is that the proposed specification should be submitted to joint sealant manufacturers for their comments and suggestions, prior to release. Frequently specifications are written, and a manufacturer notified that his product has been approved, at the same time certification to the specification is requested. This then becomes a difficult situation, when the manufacturer finds that the specification which was supposed to have been written around his material cannot be met by it. This can be avoided by allowing the sealant manufacturer to comment on the proposed specification prior to release, when necessary changes can be made easily. Successful suppliers of sealants have the capability and experience to help write material specifications for joint-sealing compounds.

Joint Sealant Requirements from an Applicator's Viewpoint

By George Grenadier, The Grenadier Corporation

Abstract: In order to assure good joint sealant applications, the applicator must work together with the sealant manufacturer, the architect, and the general contractor. It is the responsibility of the manufacturer to turn out a quality product and his representative must be technically qualified. Architects must insist that the joint sealant compounder participate in design of joint details, preparation of specifications, and inspection; their specifications must be fair but tight. It is the responsibility of the general contractor to confer with the sealant specialist and compounder to schedule the installation. One sealant applicator should take care of an entire job.

THE VARIOUS JOINT SEALANTS that are now, and have been available for use in the construction field cannot and, probably never will be "all things to all men." This, of course, refers to the applicator, his skilled mechanics, the general contractor, the compounder, the architect, and finally, the man who will pay the bill, the man or corporation who must live with the building. I, of course, cannot speak for all sealant applicators, but this is what I believe, and it may be at sharp variance with the opinions of many.

What is it really like out there in the jungle -- the veritable battlefield of concrete, steel, aluminum, porcelain, glass, wood, and what have you? And, is it really a foolish, Utopian dream to believe that joint sealants can be successfully and inexpensively installed?

COST CONTROLS NEEDED

I contend that the present high cost of sealant installation is really not necessary. Back in 1953, the cost of a polysulfide sealant was somewhere in the neighborhood of $30.00 per gallon. Since that time, it has gone down appreciably, and you can now buy the material for approximately $18.00 a unit, yet the cost of a complete installation has moved erratically upward.

The obvious explanation would seem to be the annual increase in labor costs, which more than offset the decrease in material costs. True, there has been an upgrading of labor's pay. However, unwittingly, the individuals who have complained so bitterly about the high cost of a simple calking job have contributed much to the general picture of run-away budgets.

GRENADIER, GEORGE. President, The Grenadier Corporation; member, BRI.

Of late our company, as a sealant applicator, has chosen to be far more active in the remedial field, rather than to concentrate on new projects under construction. Frankly, in the latter operation, the fight to turn out a top caliber job at a reasonable profit has been a losing one.

CAREFUL DESIGN AND INSTALLATION

I know of some architectural firms that throw up their hands in disgust at the mention of some particular sealant materials. In anger, they have switched to other products, hopefully searching for the foolproof, the miracle material that will not fail, regardless of the ineptness of the applicator, the contractor and their own staff. In my opinion, there is no such product on the market. There is no substitute for cleanliness, close supervision, good job coordination and, of vital importance, the understanding and appreciation of the limitations of even the top sealant materials available today. For anyone to expect the sealant installation to cover up all the sins of other trades is sheer folly, and dangerous.

It is a paradox that there are excellent sealant materials on the market, and yet their full potential is far from realization. The polysulfides, the silicones, the acrylics and the butyls can deliver excellent performance when properly specified, properly compounded, and properly installed. The pattern of joint sealant requirements boils down to a very simple set of views. On the basis of our own experience, I am of the opinion that these procedures, adhered to in at least a reasonable fashion, will contribute immeasurably to the individual feeling of pride in a completed project by all those who really want to do the job well.

The compounder or manufacturer has the responsibility of turning out a product that is trouble-free when used under at least normal field conditions. A foolproof system of quality control in a plant should not be difficult in comparison with what a contractor must do in the field to deliver a top caliber installation.

BETTER TECHNICAL INFORMATION

With all due respect to the function of the manufacturer, salesman, or representative, we have observed on numerous occasions that he is well equipped to sell but not technically qualified to cope with the chemistry of the sealant field. Consequently, this leads to the circulation of much misrepresentation and misinformation. The momentary fiscal gain of a sale is often enough to get many an innocent person involved in a job loaded with what could be a series of almost insoluble problems.

An illustration in point is the purchase of a considerable quantity of a back-up compound by a large general fabricator and erector. This material was to be used in the shop and in the field, for a number of large building projects where a polysulfide sealant was specified and detailed for installation in cavities that were in very close proximity of the oil-laden, nonskinning back-up in question. Contamination of the joints to be sealed with the polysulfide material was practically inevitable. Properly cleaning the cavities of the usual construction debris, in this instance aggravated by the abundance of oil residue, was a thankless, impossible task. Everything was against a successful polysulfide installation.

Fortunately for all concerned, and I mean "all," because this was a project of tremendous size, the error was discovered in time. I can only hope that on other projects where this very same material was to be used those involved were fortunate enough to be alerted to this potential pitfall. Perhaps a well-trained, salaried technician representing the manufacturer could have prevented this situation, which occurred as a result of ignorance and indifference.

As for the architect, he is frankly at the mercy of the contractors who make a reality of his draftingboard image. The first sign of trouble is often followed by cries of "faulty design, poor specifications," with everyone running for cover and, at the same time, pointing a finger in the architect's direction. To say the least, this is an unenviable position and, I imagine, quite frustrating. Of course, no man is infallible, but I must comment in passing that contractors, be they general contractors or subcontractors, frequently don a cloak of infallibility when the going gets rough. However, despite this assumed perfection, "guesstimated" budgets are exceeded, and the post-job completion problems become quite challenging, interesting and expensive, usually to the building owner, and highly profitable to the legal profession.

It is my thinking that architects must exert their influence and insist that the selected joint sealant compounder participate with some degree of active interest in designing of joint details and preparation of specifications, and conduct fairly frequent job inspections. The architect should also come up with fair but tight specifications and, in that vein, it is assumed that he has thoroughly explored the joint sealant market, and selected a material of proven quality. Therefore, any attempt at substitution by a contractor should be met not with prompt acquiescence due to the usual pressures, but with a demand that the "equal caliber" of the often lower-priced compound be proved before it can be accepted. I might add that the architect has it in his power to eliminate or reduce the frequency of this practice by incorporating in the specifications a statement to the effect that, should an approved substitute be cheaper in price than the original specified material, the building owners will be entitled to a credit.

FIELD INSTALLATION PLANNING

Of equal importance, as a contribution to the success or failure of a joint sealant project, is the timing or scheduling of the sealant installation. Certainly, I realize that this is the general contractor's responsibility. However, the architect does carry more weight than a lowly sub, and he cannot and must not sit idly by during the stage of field planning. A conference with the sealant specialist, compounder, and general contractor would be a giant step in the right direction.

On one project I am acquainted with, the sealant applicator was compelled at the direction of the general contractor to do his work while the concrete and steel operations were under way on the upper floors. Fortunately none of the sealant mechanics were killed. Some were injured, yes, but not fatally. Bits of concrete and steel and buckets of water would come cascading down on these men. The catch-all outrigger was a joke, and at every twist and turn the sealant subcontractor was hit with one "back charge" after another. Every attempt on the part of the sealant sub to get the general contractor to provide reasonable protection and proper trade coordination was met with the nonsensical reply that it would cost money. To compound the tragic state of affairs, the electrical contractor on the job insisted that all power scaffolds belonging to the sealant applicator be connected to the outlets, and the lines moved by his men, and naturally for a very healthy fee.

Where it is at all possible, I would recommend that the installation of the joint sealant be accomplished when all other trades are off the exterior elevations. There are obvious advantages to be gained from this procedure by both the sealant contractor and building owners. Of primary importance is the greater likelihood of delivering a superior job. With no encumbrances to impede his progress, the sealant contractor can accomplish his work expeditiously, and as a result, reflect this fact in his bid. Under such circumstances, the building owner can also be assured of a longer guarantee period than the usual one year.

It is sensible practice to have one sealant applicator take care of the entire job. We have, on occasion, been confronted with four contractors applying sealant compounds on the very same project. Aside from other considerations, costs can really snowball when one contractor seals all metal to metal joints, another metal to glass, and a third masonry to metal or masonry to masonry.

Jurisdictional union problems notwithstanding, every effort should be expended by the architect and contractors involved to arrange for one sealant applicator per project. Trade jurisdiction has been misrepresented, overexaggerated and, on occasion, used as an empty threat to confuse and frighten. I must admit that it has been tried on us a number of times, and when we refused to budge, they backed down. I cannot help but gain the impression that the hierarchy of the various international trade unions prefer to perpetuate the jurisdictional confusion, rather than to make a serious attempt to arrive at a reasonable settlement.

In essence, the matter frequently boils down to a willingness or desire on the part of the general contractor to create an atmosphere of harmony among the trades. The architect, too, can wield the proverbial big stick by a forceful presentation of his views, not only in the text of the specifications but during the various preliminary job meetings. At any rate, creating a division of responsibility by permitting a number of sealant contractors on one project does not serve the best interests of the building owner or, in fact, the entire construction industry. Certainly, this practice provides a fertile field for "buck-passing."

Finally, it is hoped that this brief report of our views and experiences will be of some help to all concerned. Although the joint sealant application is a comparatively simple process, it is nevertheless highly critical. In practically every instance where a leakage condition exists, knowledge of it spreads like a rampaging forest fire and, as is usually the case, the public then has a tendency to forget the talent, and at times genius, that went into the design and construction of the building. This is more unfortunate. What makes it even more tragic is that these problems are usually self-inflicted and need not have occurred in the first place.

Causes of Joint Sealant Failures

By Julian R. Panek, Thiokol Chemical Corporation

Abstract: Most joint sealant failures can be prevented by proper selection, specification, and application of the sealant. Causes of failure discussed are improper choice of sealants, improper sealant formulation, improper sealant dimensions, excessive joint movement, insufficient experience with uncommon metallic surfaces, surface contamination, inconsistent concrete and masonry surfaces, improper specification, and improper substitution of sealant. New improved sealants, along with better design and specifications, should restrict joint sealant failures to a minimum.

SEALANTS ARE SAID TO FAIL IN A JOINT whenever they lose adhesion or split apart. Although the causes of failure are varied, experience has shown that most failures could have been prevented by reasonable attention to selection, specification, and application of sealant. This review is offered in the hope that closer examination of the causes of sealant failure will reduce its occurrence in the future. Nine major causes of failure are specifically elaborated upon in this review.

IMPROPER CHOICE OF SEALANT

In selecting a sealant for moving joints, there is always some question as to whether the sealant should be permanently soft, like chewing gum, or should exhibit rubbery properties with recovery. The rapidity of joint movement determines the type of sealant to be used. This movement can be caused by solar heating, by vibration, or by wind buffeting. A soft, nonsetting and deformable sealant should only be used where there is no anticipated movement, or where the sealant is completely confined and cannot flow. A rubbery sealant with recovery should be used whenever there is movement.

The need for recovery has been established by many studies on oscillating joint movement, where the rubbery sealants outlasted the nonsetting sealants by an enormous margin. When slow or rapid oscillating movement occurred, nonsetting sealants soon flowed or split apart. In buildings, these nonsetting sealants have been observed to sag, since they are also subject to thermoplastic flow. The Canadian Specification 19-GP-3 for elastomeric sealants includes a test that calls for 500,000 oscillations in a joint assembly

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PANEK, JULIAN R. Manager, Technical Service Department, Chemical Operations Division, Thiokol Chemical Corporation; member, American Chemical Society, ASTM, BRI.

to establish the recoverability of a sealant. Therefore, it is quite apparent that serious consideration should be given to the type of sealant used.

IMPROPER SEALANT FORMULATION

In its simplest form, a sealant is a system consisting of a binder plus various fillers, plasticizers and additives, which converts to a rubbery state either upon the addition of a curing catalyst or upon exposure to the air. In every case, there has to be a satisfactory relationship between the volume of binder and the total composition of the sealant. The excessive use of fillers and of plasticizers will reduce the effectiveness of the binder component, and the system will have shortcomings.

On the other hand, the mere fact that many sealants have the same backbone binder does not imply that these sealants will perform equally well. There is a vast difference in the behavior and performance of such sealants. Because all sealant formulations are closely guarded secrets, the specifier may feel that he is being hoodwinked when suppliers will not reveal their formulations, so that these may be included in the specification. This might be an easy matter, if the specifier were to assume all the responsibility for the performance of sealants, but this is sheer folly in view of the fact that there are thousands of sealant formulations, with their many binder components and fillers, and a whole host of other problems relating to performance. It is therefore obvious that the specifier cannot draw up a material specification of his own.

The alternative is that the specifier demand performance, and leave the formulation to the processor. There are many devices the specifier can use to get better sealant performance. He can measure quality by comparing prices, and look with suspicion on very low-cost sealants. He can demand proof of performance and look to past history of performance. He can work with reputable processors and applicators. He can require guarantees, and he can use performance specifications in specifying his sealant. He might even supplement existing performance specifications to take care of unusual conditions on the job site. This is being done by many architects today. Thus, even though the specifier cannot spell out the sealant formulation, he has many methods of insuring high quality performance, if he uses them intelligently.

IMPROPER SEALANT DIMENSIONS

Even though sealants may be properly formulated, they may fail dismally if the sealant dimensions are not proper for the joint. The subject breaks down, in its simplest form, to the relationship of joint width to sealant depth. The configuration giving the lowest internal strain is a ribbon, but adhering a narrow ribbon to the edge of the joint is difficult. Moreover, the ribbon can carry no load. Thus, to improve adhesion and load-bearing characteristics, we must of necessity increase the sealant depth.

At the other extreme, maximum adhesion to the side of the joint would be obtained with an infinite depth which is also undesirable, because the sealant could not flex with joint movements. Thus, there is no ideal configuration, since many of the requirements are conflicting. Because of physical limitations and the problem of cost, the best design is the one that gives the best over-all performance at a reasonable cost.

General rules have been established for sealant dimensions in joints which, if followed more often, would eliminate many failures. Three rules would cover most sealant dimensions:

1. No contacting surface shall be less than 1/4".
2. The depth of the sealant and the width of the sealant shall be of equal dimensions up to 1/2''.
3. At widths from 1/2'' to 1'', the depth shall remain at 1/2''.

EXCESSIVE JOINT MOVEMENT

Many sealant failures occur because of excessive joint movement. We have seen 1/4 in. wide joints open up to 1 in., and completely close on the other extreme. Only a sealant that performed like an ideal gas could perform under these conditions, and there is no ideal gas. Most sealant manufacturers have stated that a sealant in a joint should be capable of being extended or compressed to a value of 50% of its original dimension. To include a factor of safety, these sealant manufacturers have worked together to develop a specification which calls for 100% extensibility beyond the original dimension in many test assemblies. Because of physical limitations in the space geometry of the sealant, values above 50% are not realistic and, for this reason, architects should design joints around the practical limitations of sealants, rather than leave the joints to be sealed by an "infinitely extensible, compressible, and frictionless sealant."

In order to minimize internal strain within a sealant, the sealant should not be permitted to adhere to the back of the joint. Furthermore, if this joint will close beyond the original width of the sealant, then the back-up joint filler must be either air or a compressible material, such as a closed-cell butyl extrusion, a urethane foam, or a neoprene tube. We have seen instances where a back-up plate was welded to one side of a joint assembly. When this joint opened up, it created an unusual strain on the sealant in the corner that was opened. The sealant had to tear apart at this point of stress.

Some very sad experiences have been observed, where sealants have been applied over a pourable grade of asphalt or asphalt-impregnated expansion strips used as a void filler. When these joints closed beyond the original dimensions of the sealant, the asphalt acted like a hydraulic fluid in a pump, and physically displayed the sealant. Various nebulous expressions were coined, such as "incompatibility" and "limited compatibility," to describe sealant failure in these situations. The actual cause for failure was the use of an incompressible joint filler in a narrowing joint. The use of a porous, compressible back-up filler gives the sealant some breathing space when the joint closes beyond its original dimension. Also, the use of the porous filler provides a good way to control the depth of the sealant in the joint for optimum performance.

INSUFFICIENT EXPERIENCE WITH UNCOMMON METALLIC SURFACES

Studies of the more common building surfaces have shown that good sealant adhesion can be expected to the various steels and stainless steels, glass, and the various alloys of aluminum. On the other hand, specific sealants may not have been tested against surfaces such as lead, zinc, copper and tin, and various alloys of these metals. There is no reason to assume that all metallic surfaces are identical when discussing sealant adhesion. We have seen too many cases where generalization has resulted in poor performance. Our recommendation is that all uncommon metallic surfaces should be given extra attention.

There is no reason why the architect cannot demand performance against any specific surface. Many sealant manufacturers are willing to test their products on new surfaces, in order to prove feasibility. An uncommon metallic surface should offer no problem, if performance against this surface is specified and laboratory testing establishes that the sealant will perform.

SURFACE CONTAMINATION

There is no sealant on the market today that will absorb all surface contamination, penetrate through oil films, paint films, dirt and dust in order to get at the virgin surface, and give 20 years of satisfactory adhesion and performance. Therefore, for the present, until the miracle sealant is introduced, all surfaces have to be cleaned. Since the architect cannot supervise every inch of installation, he should require a guarantee of the performance of the sealant from the applicator. If he selects a reputable applicator, he can be reasonably certain that the sealant has been applied in a clean joint. The architect might also anticipate surface contamination, and require protection of surfaces by the use of masking tape. This protective tape could be removed just prior to the application of the sealant. It maybe argued that this practice would increase cost, but this cost could be less than the cost of labor required to clean the joint prior to application of the sealant.

INCONSISTENT CONCRETE AND MASONRY SURFACES

Natural stone and concrete vary considerably in hardness and texture, and the surfaces of these materials are very often soft and friable. Frequently, we have observed sealant failure where the sealant surface was completely covered with delaminated stone and concrete particles. This is not proof of sealant failure, but of surface disintegration of the stone or concrete. There are two ways to prevent this condition. One is by using a penetrating primer to reinforce the surface; the second is to use a lower-modulus sealant. Primers are used extensively at the present time on all stone and concrete surfaces. These primers, in addition to reinforcing the surface, keep water away from the interface, and cause better and more lasting adhesion.

As I mentioned, lowering the modulus of the sealant would help to prevent delamination of stone or concrete. We know that the tensile strength of concrete is approximately 400 psi. We also know that some sealants have ultimate tensile strengths of 600 psi, if they contain excess filler, and cure to a rough rubber. Such a combination in addition to excessive joint movement, will always lead either to failure in adhesion or surface delamination. It would be desirable if one of the stone institutes or cement associations could make available a list of tensile values for the various natural stones and concretes, so that these values could be used to establish some maximum modulus values for sealants. This is fertile field for future specification writers.

In addition to the variable composition and strength of concrete, the problem of adhering to concrete is further aggravated by the use of form oils, anti-freeze additives, fast-setting additives, surface coatings to prevent evaporation, and surface coatings for waterproofing and decoration. Also, the dimensions of expansions of expansion joints in concrete are not consistent with the recommendations for joint and sealant dimensions noted above in our discussion of excessive joint movement. For these reasons, many sealant manufacturers today do not attempt to serve this market, while others study all the conditions critically before recommending their products.

On pavements, roads and runways, problems may be further aggravated if the contractor is reluctant to use a high-cost sealant with low-cost concrete. He may try to solve the dilemma by reducing the number of joints and joint dimensions. A better solution would be to use coal tar-modified elastomeric sealants. Such sealants have performed satisfactorily in these applications because they are rubbery, yet are capable of deforming, and they exhibit thermoplasticity. This class of sealants is covered by several Army Corps of Engineers' specifications, namely: SS-S-00195, SS-S-00200a, and SS-S-00200b. These lower-cost sealants are limited to use in horizontal joints, and have been so used for more than five years.

Quarry tile and brick offer a different type of surface. Here, the surface is hard like glass, and yet may have some porosity. Exposed surfaces of some quarry tiles are treated with paraffin, and many building bricks are treated with a silicone oil. Because the degree of surface contamination varies from batch to batch, no prediction can be made regarding sealant adhesion and performance. On the other hand, laboratory tests on materials collected at the job site will quickly establish reliable data for proper selection of sealant and primer. We have been directly involved in testing sealant adhesion to silicone-treated brick, and found that the surface contamination was very low. This condition, in combination with the very rough but strong, surface of the brick, and the use of an appropriate primer, gave consistently good performance. We recommended a job site test with available sealants, and also recommended that the architect use a high standard for specification of the sealant.

Many types of adhesion failure can occur in quarry tile installations on roof decks. In addition to a slightly porous, hard, glassy surface that may be contaminated with paraffin, quarry tile roofs are often laid on asphalt-covered concrete decks. Such an application may result in a hydraulic effect from solar heating, and may cause surface contamination from asphalt. The tiles can also drift, when the deck is slightly pitched to handle surface drainage. The accumulated drift may close up some joints and open others. In addition the effect of vapor pressure of the volatile components in the asphalt can cause physical separation at the interface.

Many adhesion studies have been run on quarry tile, to evaluate the use of primers. Sand blasting of the edges in combination with certain primers gave good adhesion, and exceptionally good adhesion was obtained to freshly broken tile edges. This suggests that the tile manufacturers might make extra-long tiles which could be broken along a dividing market to expose fresh surface for use in critical joint areas. This would drastically reduce adhesion problems. Freshly sawn joints would also result in good adhesion. The architect should be particularly careful in drafting his performance specifications in this area.

IMPROPER SPECIFICATIONS

Many sealant failures have resulted from the use of improper specifications. Some specifications have consisted of one word, in the expectation that the use of the word would automatically imply immunity from sealant failures. Nothing could be further from the truth. There are in existance today at least three specifications covering performance requirements for elastomeric sealants. These are: The Canadian Research Council Specification 19-GP-3; the American Standards Specification ASA 116.1, 1960; and the Interim Federal Specification TT-S-00227.

Our recommendation is that the specifier use these specifications, in addition to other requirements that he may have. If the surfaces are unusual, they may be included in the specification. If the prevailing conditions are radically different, then the architect should insist on testing sealants on mock-up. If the building materials are uncommon, then tests should be made on these materials as part of the proof of performance. In addition, the architect should have tests conducted at several different testing laboratories.

IMPROPER SUBSTITUTION OF SEALANT

We have all seen the expression, "Brand X or equivalent" used in specifying a sealant. Each sealant has its own distinctive set of properties, but has no equivalent in performance. In many instances where substitutions have been made, the responsibility for the performance of the so-called equivalent was never settled. Even more frightening than this is the question of responsibility for remedial work, in case the substitute sealant fails. If an architect wants to specify a proprietary product, but has to leave the door open, then he should state, "Brand X or a sealant meeting Specification Y with the following additional requirements" -- and list these requirements. Then there should be no question that the substitute sealant will meet minimum performance requirements. However, if the architect has faith in a product, then he should abide by his own convictions, and not permit the use of an alternative.

CONCLUSION

Over the past ten years, studies of the causes for sealant failure have resulted in improved sealants. Studies of joint and sealant design have determined the conditions for optimum performance. Specifications have been developed to describe high quality performance in sealants. With these accumulated data, the architect is on the threshold of a new era in which he can restrict his failures to an absolute minimum.

Open Forum Discussion

Moderator: Francis S. Branin, ASCO Products Corporation

Panel Members: Messrs. Amstock, Grenadier, Panek, and Tons.

Mr. Branin: What emphasis do you place on adhesive strength and cohesive strength of a sealant? What properties of modulus and hardness would you recommend?

Mr. Tons: It depends whether the sealant during its service life stays in compression only or undergoes both tensional and compressional cycles. In the first case adhesion is not important and a possible practical modulus for such a material could be in the vicinity of 50,000. Such a sealant should be as close as possible to an ideally elastic material.

If a sealant during its service life is put in tension (without complete stress relaxation), there will be stresses at the sealant-joint interface (bond stresses). Owing to imperfections in adhesion along the joint interface, progressive bond failures may result where joint movements are of considerable magnitude. On the other hand, one can design a sealant which, in spite of imperfections at the bond interface, is "stronger" in adhesion than cohesion and will fail within the material itself (cohesive failure). Most of our failures in tension type seals have been in adhesion, and therefore, more emphasis should be placed on bond between the sealant and the joint interface. Theoretically, modulus (and hardness) values for a tension type seal will depend upon the type of joint to be sealed.

The compression type seal would diminish adhesive and other problems in joint sealing. The idea is not very new and revolutionary, but in the past it was difficult to find materials with negligible stress relaxation characteristics, while such materials are in existence today.

Mr. Panek: Basically, Mr. Tons, your curves are right, but they're all derived on one particular sealant. If you used a softer sealant, you would displace all the curves in one direction. In other words, you would displace all the curves to the right, and all the values would become lower. We believe the sealant must exhibit recovery.

Mr. Branin: I have a question for Mr. Amstock which was asked by four or five different people. In your discussion of flexibility, you recommended 45 psi and 250% elongation, and a 20 to 30 Shore A hardness. Is this in connection with ASA assemblies? Also, is this the optimum hardness value?

Mr. Amstock: Basically, the values that I mentioned are in accordance with ASA, but it also provides for a spread of 10 to 40 Shore A hardness, if I'm not mistaken. However, this is also dependent upon where the sealant is going to be used. If it is to be used in a sidewalk joint, you naturally don't want to use a material that has a Shore A hardness of 10, because women's spike heels would go right through it. In a sidewalk joint, you need a material that will resist indentation, and you also need a higher tensile value in the material.

Unsigned question: Do you consider that the ASA specification or the federal specifications are adequate for specifying sealants?

Mr. Panek: Both specifications are good, but they are not ideal. It has been indicated that additional requirements should be added by the architect. I, myself, feel that there should be a minimum and a maximum Shore A hardness, either put into the specification or added by the architect, and the maximum hardness should be governed by a high temperature or elevated temperature test. I'd be willing to stick my neck out and say that I think 60 or 65 should be absolute tops after one week at 212°. What do you think of that, Mr. Amstock?

Mr. Amstock: I'm afraid that if you get up that high with Shore A points, we'll have some failure in the joints. The big problem is trying to correlate the tests with the actual field application. If this is a test of aging performance, I would say it's a very valid test.

Mr. Panek: I think we have to theorize that laboratory testing is merely a means to an end, and that if the laboratory test indicates certain maximums, these will exceed, in many cases, the conditions you would expect out in the field. When we indicate a certain value in the laboratory, we don't expect this will be duplicated, in fact we never expect to get this in the field. We recently examined a sealant that's been in use in the field for eight years, and I was quite surprised to see that the hardness hadn't exceeded 40. This is quite remarkable considering that, in the beginning, the sealants were not as good as the materials being produced today.

Mr. Amstock: With the proper choice on the manufacturer's part of ingredients to compound this sealant, this hardening or aging actually could be prevented from taking place in the sealant. As I mentioned earlier, a good specification that evaluates all these properties will benefit everyone concerned.

Unsigned question: Do you guarantee your work irrespective of sealant, or on what basis do you guarantee your work?

Mr. Grenadier: As a general rule, we have a good deal to say about what sealants we will use. If, on occasion, we do run into a situation where we feel that the sealant is improperly specified, we will so indicate to the specific owner or architect and attempt to get it changed. On the other hand, sometimes we don't know anything about a particular sealant. There are a number of new ones with all sorts of brand names, and there are a lot of people allegedly in the compounding field who, in actual fact, may not be. In such a case if the architect insists on using a particular material, we avail ourselves of a test provided for us by someone in the field who has absolutely no axe to grind but to see that the job is done properly. The only provision we have to make for something like that is simply to remove the label from the can. We can't indicate to them precisely who the manufacturer is. By this means we get a factual report. If it's rather derogatory, we will notify the architect or the owner. All of our work has been guaranteed; I would say the guarantee has run to a maximum of five years.

Jim McClellan, Wyandotte Chemicals Corporation: What effect does the tensile set or cold flow of an elastomeric sealer have on long-term durability?

Mr. Amstock: We've had experience with this in several cases, primarily on bridge decks that are on a skew with reference to the road itself. Here, the material goes into compression more than expansion, and also other contaminants get in the joint and force it closed so it won't move any further. In turn, the sealant in question would actually have cold-flow setup, however, when the joint is cleaned out again, and the bridge starts moving back out again, you have a stress or tearing characteristic of the sealant. I am speaking strictly of the physical effects. The other is not going to affect the aging properties of the sealant. If it is displaced too far, it can't come back.

Unsigned question: Since a flat shape factor, that is, a shallow joint, is desirable, how thin shall a joint be made, 1/16 in. or 1/8 in. deep?

Mr. Tons: The thinner (shallower) the better! From a practical standpoint a "membrane" of 1/16 inch thickness may be realistic. Furthermore, it would be impractical to "pour" such a seal. Probably the best approach would be to have a prefabricated strip of sealant, say 1/16 inches thick and wider than the joint and to glue this strip on top of the joint so that the bonding area would be subjected to shear rather than tension. Field experience with road joint seals has shown the superiority of overlapped joint seals. One can go a step further and glue the strip of the sealant slightly folded so that it flexes rather than stretches during the opening of the joint. This would either eliminate or reduce stresses on the bonded area.

Unsigned question: Does the use of calcium chloride in concrete affect the performance of polysulfide sealants installed against such concrete?

Mr. Panek: The chemical effect will be nil; one effect that you might get, however, is that if this material migrates to the interface it could actually cause the sealant to lift off. Or, if the sealant has been put over a thin film of calcium chloride which has dried on the surface, you will also get adhesion failure. This goes right back to the fact that you have to prepare the joint and get right down to good, solid, virgin surface to get good adhesion. If you don't, you won't get adhesion.

Unsigned question: Can you make any recommendations for tightening up the specifications for quality sealants?

Mr. Grenadier: I would say that checking the past performance of a specific sealant would be a valuable thing. In other words, when an architect devises a specification he should actually call for information on the performance of that sealant somewhere in the vicinity of his particular project, where it had been subjected to the same climatic changes, temperature changes, etc. The performance in the field is extremely important. I would suggest, too, that the architect could spell out the necessity for a specific test of a sample of the sealant, not only at the outset of the job, but also during the course of the job, while a part of the batch delivered to the job could be removed for actual testing. The individual applicator could include that in his cost for that particular project. There are ways of spelling it out -- this is just one off the top of my head.

R. C. Schubert, Dept. of the Navy, Bureau of Yards and Docks: What specification would you follow for a blast-resistant sealant for airport aprons?

Mr. Amstock: The one that's currently most used. If my memory serves me right, it has a section in it covering blast resistance, and that is SS-S-200a and the revised version, 200b. This was primarily developed for sealing runways, taxi strips, and takeoff area. The SS-S-195 is a specification to a lesser degree, designed to eliminate the fuel resistance, spillage, and gas resistance. These are the ones that are most applicable today.

C. L. Smith, General Electric Company: With reference to your Figure 16, did all of the sealants, including the polysulfide, fall on the same curve or did stress relaxation become apparent?

Mr. Tons: The strain rate in this particular study was rather high - about 0.2 in/in/min. At this rate (and room temperature) both the rubber asphalt sealant and the polysulfide sealant followed the predicted parabolic neckdown curve. In the case of the polysulfide sealant, the force needed for extension of the standard specimen was considerably greater than that for the rubber-asphalt material. After the extension, the rate of stress relaxation was higher in the case of the rubber-asphalt as compared to the polysulfide rubber.

S. T. Schellenbach, Steelcote Company: Would you please comment on removal of oil-base calk and asphalt from porous surfaces before application of polysulfide sealants?

Mr. Amstock: That's a good question. If you have a solution yourself, I'll be interested in hearing it. The problem is actually the impregnation of the oils and asphaltic materials into the concrete. I assume that the question refers to a surface that is to be sealed and is basically concrete and extremely porous. The best recommendation that I can make would be to rake out all the old asphaltic material or oil-base calking material, and cut back the joint. People will say this is a rather expensive process, but if you want the best possible job, this is what you have to do: cut back the joint, neutralize it, and try to get all the oil out. If you don't do this, expansion gases in the summertime will actually break the interface of a newly sealed joint, if it is sealed with a polysulfide material. We have also encountered areas where, after we cut back and sandblasted, we still couldn't remove these oils. Therefore, we had to pass a blow torch over the interface to draw out all these oils, cause the concrete to expand and pull out the oils, then sandblast again. This is a rather expensive job, but it's the only way you can be sure of getting a proper seal. After you get the concrete clean, or reasonably clean, you have to make a proper selection of primer that will not be attacked by these gases.

S. B. Twiss, Cycleweld Division, Chrysler Corporation: What are your views on accelerated weathering tests or aging tests? Are there any which are safe to use in projecting the life of new sealant compositions? What is the probability of correlation?

Mr. Panek: It's possible to run accelerated aging tests that will give you some insight as to the future performance of the sealant, but you'll have to run three or four different tests to get some indication of its over-all future performance. One of the tests that we like to run in the laboratory is to make cast sheets of the sealant, and to heat-age them at various temperatures, say one week at 258° F, one week at 212° F, and one week at 250° F. Then we measure the physical properties after these various periods of time, and compare them. If the Shore A hardness goes up to 70 or 75, you can discard this sealant. On the other hand, if the hardness stays fairly low and does not exceed 60, and if the elongation still remains at a reasonable level of about 200% after one week at 250° F, you have a pretty good sealant, as far as rubbery property goes. But then, you have to go back and check for adhesion separately. We recommend in our own laboratory (and this may not be a bad consideration for others) that you make an actual adhesion assembly with the specific surfaces to be involved, and test the adhesion after one or two weeks at room temperature. Then we take these particular assemblies and immerse them in water for a period of one or two weeks. If you still maintain good adhesion after two weeks of water immersion, the adhesion factor and the heat-aging factor would indicate that the sealant should perform quite satisfactorily. We don't put too much stock in low temperature testing, because the polysulfide sealants are quite flexible. Heat, adhesion, and water immersion are the three factors that will affect performance over long periods of time.

Mr. Amstock: What is the effect of using the weatherometer on ultra-violet tests? You run those, too, don't you?

Mr. Panek: The weatherometer is, in a sense, a glorified elevated temperature and water immersion test. Really, I think it tends to confuse the results rather than to clarify them. Now, if we were testing ultra-violet effect, we would segregate this particular test from the others and run an actual U-V test under glass. If you then take the assembly and immerse it in water, and again test it for adhesion, you will have a pure test. You can segregate it from the other effects and evaluate it on its own merits. And if it has adhesion after U-V exposure and water immersion, again, you have a pretty good sealant.

Unsigned question: Do you believe that a minimum polymer content should be mentioned for high quality sealants? If you do, what minimum do you recommend?

Mr. Amstock: No, we would not recommend any specific amount. There again, what matters is knowing the end-use of the product: where the sealant is going to be applied, and what it is supposed to do. Some manufacturers can compound a very good sealant with, say, 30% polysulfide content as its base, and others can do it at 40%. I don't think the amount of polysulfide should be specified or spelled out in the specifications. In addition, if it was, it would be very difficult for one to detect how much actually is in the compound. One can detect it, but it's a very costly process. So I would say it shouldn't be included in the specification.

Mr. Panek: I think Mr. Amstock is right, up to a point. However, taking the architectural viewpoint, they have the liberty of specifying some minimum polymer content and, if they want to take some arbitrary figure, I recommend 40 or 45%. The only thing that will happen is that, if the sealant manufacturer doesn't concur, he'll say simply that he hasn't got it. On the other hand, if he has, and the architect is satisfied, then all parties are in accord. I, personally, would like to see some sort of minimum set.

Mr. Branin: I have a question in regard to the ASA sealant specification. What would be your recommendation of additions to this specification?

Mr. Amstock: Since the ASA document was put into use, ASTM has agreed to take the specification and amend it or improve it as they see fit. For about two years, the ASTM Committee C-24 actually has been working to develop a more rigid specification on the basis of a Round Robin testing program. The same people who worked on the ASA document are on the ASTM Committee C-24.

Mr. Panek: I might add a point here. We did mention that minimum and maximum hardness, polymer content, adhesion, and peel tests would be very good additions to supplement the ASA specification. These are very simple tests and can be run against any kind of new surface. I have mentioned this before, and I would like to repeat it. If the architect has a new, untried surface, it's very simple to run an adhesion peel test against it. You can get absolute results within two weeks, which will indicate whether the sealant in question will or will not meet adhesion requirements to that surface. I think this could be a very valuable addition to the specification.

Unsigned question. Do all colored sealants perform equivalently?

Mr. Grenadier: From our own experience, I would say that regardless of the pigmentation, if properly compounded and put in the proper place, all should perform well.

Mr. Amstock: As a manufacturer, we supply a complete range of color additives which we add to several bases of polysulfide-type sealants and we do not distinguish from one color to the other in terms of a higher tensile strength, or higher Shore hardness, or what have you. They actually all perform the same regardless of the color.

Mr. Panek: May I make one more statement? There was a time, about four or five years ago, when the first sealants used in buildings were all black. These were developed from those used for the aircraft industry, where good chemical resistance was desired. There was also a time when the aluminum-filled sealants were quite widely used, and I think this is where the color question arose. In the past few years there has been much less emphasis on color and more emphasis on performance. I think this is the point we shouldn't forget. Let's demand performance and, if the colored sealant meets the requirements, all well and good, but let's not sacrifice performance in favor of color.

Unsigned question. You make a basic assumption that a sealant is made to contain elastomeric properties. What of the vast usage of straight mineral-filled plastic joint sealants and grouts which do not possess the elastomeric properties of recovery, but have proved to be in the fair performance class, and low in cost?

Mr. Toms: You have a point there. The talk has been mostly about so-called "heavy duty" sealants, i.e., compounds to be used for sealing joints which have considerable variations in width during daily and yearly cycles. If someone wants to seal so-called "dead joints" or those which move very little, several inexpensive sealants may become suitable.

J. W. Prane, Pecora Paint Company: Re installation of quarry tile over asphalt or coal tar-covered roof deck, do you have any specific recommendations for back-up material, joint sizes and sealant application, using the polysulfide type?

Mr. Panek: Of all the materials I have seen, quarry tile roof deck is one of the most rigorous and difficult to seal. To answer this question, we should go back to the roof in question and actually put in some trial installations. We don't run into too much movement in this particular type of roof; it might even be less than the 50% that I qualified in my talk. However, the problems with quarry tile are that you have a very difficult surface to which to adhere, and you are laying this deck over an asphalt built-up roof. Therefore, you have trapped volatile oils present, and when the roof reaches temperatures of 140°

or 150°, these volatile oils or gases have to diffuse out. They can't diffuse through the quarry tile, so they come out through the sealant. And, if they exert an actual pressure, this pressure is enough to cause adhesion failure, rather than actual roof movement. This also causes various types of contamination of the adhesive bond. To determine performance, we really must go back to the roof and run a couple of trial installations on it.

Unsigned question: Are asphalt or coal tar compositions compatible with polysulfide sealants?

Mr. Panek: Compatibility is a very loose term. To answer the question, the asphalts or coal tars will not chemically affect polysulfide sealants, but the deterioration of the adhesive bond is more likely due to hydraulic pressures or gas pressures, as described in my reply to the previous question.

Recent Developments in Joint Sealant Materials

90/91

One-Part Polysulfide Joint Sealants

By G. M. LeFave, Robert Gamero, and Frank Y. Hayashi, Coast Pro-Seal & Manufacturing Company

Abstract: This paper describes a new one-component polysulfide sealant which has performance properties superior to older types of polysulfide sealants. Among its practical advantages are its simple application, minimal loss, and cure over a wide temperature and humidity range.

THE EVOLUTION OF SEALANTS has paralleled, and perhaps runs a short span behind, the architectural revolution. When, in recent years, the modern building suddenly changed from the former massive structure into a lightweight, dynamic unit, the use of truly elastic sealants emerged as a vital requirement for weathertightness.

A GROWING MARKET

The high performance of polysulfide sealants is attested to by their domination of the $4 to $5 million existing market volume. Expansion to a $10 million dollar market is feasible in a very few years, considering both the growth of curtain wall construction, and the rapidly increasing number of sealant applications within structures constantly on the move, functionally and dynamically.

Lower material cost, permanence of properties, and improvement of the ease of application will primarily dictate the size of the polysulfide sealant market in the coming years. It is with the latter two areas that we shall concern ourselves in this presentation.

ONE-PART SYSTEM DEVELOPED

Recent advances in chemical technology have now made it possible to provide a polysulfide sealant with performance properties

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LeFAVE, G.M. Vice President, Coast Pro-Seal & Manufacturing Company; member, American Chemical Society, American Concrete Institute, American Institute of Chemical Engineers, American Institute of Chemists. GAMERO, ROBERT. Section Head, Product Development, Coast Pro-Seal & Manufacturing Company. HAYASHI, FRANK Y. Director of Research and Development, Coast Pro-Seal & Manufacturing Company.

vastly superior to previously existing products. One aspect of this development is the evolution of polysulfide compounds into a one-component system which cures over a surprisingly wide temperature and humidity range.

For the past few years, we have been hearing that a single-component system is, "just around the corner." In fact, we understand one or two such products have made their appearance on the market, but have received virtually no acceptance because of rather inferior application and performance characteristics. Past approaches to single package systems have possessed limitations which evidently precluded their practical commercialization. However, they constitute an admirable contribution to the chemistry of convertible polymers.

The system described herein, however, represents a radical and sophisticated departure from conventional polysulfide polymer technology and in no way, except for its tackfree time, necessitates an apology. While tackfree time can be reduced, the storage stability may suffer accordingly. In performance it exceeds, in all respects, the old types of polysulfide sealants.

PERFORMANCE CHARACTERISTICS

Table 1 highlights the conformance (where applicable) of this amazing polysulfide system to the requirements of the American Standards Association Specification for Polysulfide-Base Sealing Compounds for the building trade, approved July 27, 1960 by the American Standards Association (ASA 116.1-1960).

These obviously superior results only serve to point up the high order of performance of these new polysulfide sealants. Table 2 provides additional information. As may be seen, a rainbow of color choices is feasible for the first time, because the system is stable and receptive towards tinting and/or deep-tone pigmentation. (While the data in Table 2 were obtained on a white compound, it is expected that comparable results can be attained by compounds formulated in a variety of colors). Chalking has not been observed to date. The modulus properties are in excellent balance. While staining is of a low order, yellowing has been observed in whites and the lighter colors.

Before leaving performance properties, it is important to note some further advantages of this one over classical polysulfide systems. These are perhaps more subtle, but frequently of real value to the building and construction industry.

Prolonged exposure to temperature as high as 250° F, or even intermittent periods at 275° F, have only minor effects on these new polysulfides. Likewise many acids, alkalis, chemicals, solvents and oils cause little degradation.

The trend toward integrated electrical wiring and heating functions in prefabricated curtain wall sections for example, will demand greater heat resistance from sealants; and those materials

TABLE 1 -- CONFORMANCE TO ASA REQUIREMENTS FOR POLYSULFIDE-BASE SEALING COMPOUNDS

Type B Polysulfide Sealant	New Polysulfide Sealants[1]
Non-sagging between 40° and 100° F.	Non-sagging between 40° and 120° F.
Adhesive strength in tension, 150% elongation, 10 psi minimum force, no failure.	150% elongation, 30-35 psi, no failure; 400% elongation, 50-55 psi, cohesive failure.
Water resistance: specimen immersed in distilled water, 4 days @ 77° F. Extended 150% for 24 hrs., 10 psi minimum force, no failure.	150% elongation, 25-30 psi, no failure.
Heat-aging: specimen heat-aged 4 days @ 158° F. Extended 100% for 24 hrs., 10 psi minimum force, no failure.	100% elongation, 30-35 psi, no failure.
Low temperature test: specimens placed @ -20° F. for 4 hrs., pulled slowly to 100%, held for 16 hrs., removed and allowed to stand @ 77° F. Specimens to be cycled 3 times, no failure.	Cycled 3 times to 150% elongation, no failure.
Recovery test: specimens placed @ 120° F. for 3 days, conditioned for not less than 16 hrs. @ 77° F. Extended to 150%, held for 5 minutes, removed and allowed to recover. Recovery to be not less than 25% within 1 hr. @ 77° F.	Recovery after 1 hr. @ 77° F., 100%
Accelerated aging: specimens exposed under sunlamp for 4 days. Depth of surface cracking or crazing to be less than 3 mils.	No cracking or crazing after 16 days' exposure
Sunlamp exposure through glass: specimens having an aluminum plate on one side, glass on the other, exposed to sunlamp for 4 days, immersed in distilled water for 4 days. Extended to 100%, 10 psi minimum force, no failure.	Exposed to sunlamp for 5 days and 4 days in distilled water. 250-300% elongation, 40-50 psi, cohesive failure.

[1] Specimens cured for 45 days (25-30 Shore A hardness) and run in triplicate.

TABLE 2 -- PERFORMANCE PROPERTIES OF ONE-PART POLYSULFIDE SEALANT

Property Tested	Result
Color	White, aluminum, grey, black
Ultimate hardness	25-30 Shore A
Ultimate elongation	300-400%
Tensile stress at 150% elongation	30-35 psi
Ultimate tensile strength	100-125 psi
Tear strength	25-30 psi
Adhesive strength in tensile shear	90-110 psi
Initial viscosity	10M-20M poises

with good electrical properties purport to simplify design of the wiring channels. The new sealants can serve as primary insulation, assuming proper design allowances.

Even such properties as good abrasion resistance, low shrinkage and resilience, not normally associated with polysulfides, are enhanced. Perhaps the reason for these fundamental improvements is the complete absence of solvents and/or plasticizers. (Toluene and water extractables are both well below 3%.)

The relatively low water vapor transmission rate of the sealant may also be attributed to the unadulterated polysulfide polymer.

Reduced application costs, due to a single-component system, need little elaboration, particularly considering the spent pot-life material losses of the two-package system. Realistic computation of direct and indirect costs will reveal to quality-oriented architects and contractors the necessity for a hard look at the new polysulfides.

COMPARISON WITH TWO-PART SYSTEMS

Below are noted some advantages of a one-part polysulfide sealant in relation to the standard two-can material:

1. Eliminates need for mixing equipment
2. Simplifies handling
3. Insures a more consistent end-product
4. Eliminates possibility of incomplete mixing
5. Provides a uniformly airfree system
6. Minimizes material loss
7. Saves man-hours on clean-up time
8. Material is ready for use at job-site and can be pumped into application gun
9. Eliminates expensive or inaccurate proportioning
10. Does not thicken and become sticky during application

11. Can be tooled to desired shape and smoothness in place
12. Low temperature extrudability and cure are outstanding
13. Adhesion is more positive due to longer wet-state time

Among the few disadvantages of the one-part system are:

1. Length of tackfree time allows some dirt pick-up
2. Longer cure time
3. Cost is 25% to 50% higher than two-part systems

Because of the integral or "built-in" nature of the curing agent in this one-part system, it is necessary to understand the relationship between storage stability and time to cure. Table 3 provides this information together with additional data pertinent to environmental conditions.

STORAGE AND APPLICATION

Also peculiar to this new polysulfide system is the ease of gun extrusion at relatively high viscosity. The initial viscosity is nominally adjusted to 12,000 poises. Standard nonsagging polysulfides in this viscosity range will have a rate of extrusion roughly one-half that of the new system. Therefore, on aging, the new polysulfide has a practical extrusion viscosity of 25-30,000 poises. Extensive aging tests have indicated a statistical shelf-life of seven months. Low temperature storage will increase this period in proportion to the temperature.

Furthermore, it is normally possible to recover over-aged material by warming it at an elevated temperature not to exceed 120° F for one-half hour, and obtain a viscosity reduction of 25-30%. The nonsagging properties are unaffected after three hours at this temperature.

Rather apparent are the practical implications accruing to this performance: simple application and minimal loss.

Applications requiring rapid cure are not out of the question but pose distinct problems. Since the curing mechanism operates by heat, moisture, and oxidation, or any combination thereof, it may frequently warrant considering the use of a heat gun and/or moisture to effect partial cure. Early formation of a tough skin generally is adequate to obtain satisfactory sealant performance. In such cases, cure will continue in normal ambients to provide the same ultimate high-quality product obtained with an unaccelerated cure.

In effect, this paper delineates a new polysulfide sealant which blankets, for the first time, a large portion of the calking and glazing compound spectrum. Now that it has been demonstrated that one-part polysulfide systems are quite practical, we may expect the appearance of other systems, and the extension of their chemistry to epoxy, silicone, and polyurethane resins.

TABLE 3 -- STORAGE STABILITY

Temperature	Time
35° F.	12 months
77° F.	6 months
100° F.	30 days
120° F.	7 days

TABLE 4 -- TIME TO CURE[1]

77° F @ 50% R.H.	35° F @ 70% R.H.
2-3 days, tackfree	2-3 days, tackfree
7 days, 15 Shore A	13 days, 5 Shore A
2-3 weeks, 25-30 Shore A	21 days, 15 Shore A

[1] 1/4 in. fillet

TABLE 5 -- HARDNESS vs. FILLET THICKNESS[1]

Fillet Dimension	Hardness (Shore A)	
	8 days	18 days
3/16 in.	15	25
1/4 in.	15	25
5/16 in.	15	25
3/8 in.	15	25
1/2 in.	13-15	25
5/8 in.	8-10	18-20
3/4 in.	8-10	18-20
1 in.	5-6	15

[1] 77° F @ 50% R.H.

TABLE 6 -- EFFECT OF RELATIVE HUMIDITY ON CURE TIME[1]

Relative Humidity	Tackfree	15 Shore A	25 Shore A
90%	14-16 hr.	3-4 days	5-6 days
81%	14-16 hr.	3-4 days	5-6 days
71%	16-18 hr.	4-5 days	7 days
66%	2-3 days	6 days	11 days
47%	4 days	9-11 days	15-18 days
42%	4 days	11-12 days	15-18 days
30%	5 days	12-14 days	20 days
20%	11 days	14-16 days	25 days

[1] 77° F, 1/4 in. fillet

One-Part Silicone Joint Sealants

By Remo R. Maneri, Dow Corning Corporation

Abstract: A new one part-silicone rubber joint sealant is described, with emphasis on its stability over a wide temperature range, chemical inertness, and weatherability. To obtain its maximum performance, five factors must be considered: cross-section of the bead, movement of the joint, accessibility of the joint, compatibility of the joint system, and possible physical abuse of the sealant. The one-part silicone rubber sealant has the advantages of lower application costs, quality performance, long life, and low maintenance. Its limitations are typical of a high-performance rubbery sealant.

THE USE OF NEW CONSTRUCTION MATERIALS, and combinations of materials with large differences in expansion and contraction, has introduced more critical sealing problems to the building industry. New types of calking compounds or sealants have been sought to satisfy these new requirements. Experience with silicone rubber over the past 17 years set the stage for the development of a one-part, high performance, silicone rubber building sealant, minimizing waste and labor problems, while adding to the utility as well as the aesthetic qualities of a building.

Silicones are essentially semi-inorganic materials closely related to quartz and glass in chemical structure. Among their unique properties are: indifference to heat, cold, oxidation, ozone, and weathering; -- resistance to corona, high voltage stress; high water repellency and moisture resistance; inertness to fungus and many chemicals. Silicones are available in almost every physical form: fluids and oils; greases and compounds; resins, varnishes and rubber.

Thus here, with a little stretch of the imagination, is rubber made from rock, for the basic indestructibility of rock or sand is built into silicones through a chemical marriage of the inorganic elements of sand with those of organic matter. This is not so far-fetched, perhaps, when you consider that natural rubber from a tree and synthetic rubber from oil also carry the mark of their ancestors with regard to physical characteristics. From its inorganic-organic "parents," silicone rubber inherits three major character-

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MANERI, REMO R., Project Manager, New Products Development Department, Dow Corning Corporation; member, American Chemical Society, American Concrete Institute, ASTM, BRI.

istics: stability over a wide temperature range; chemical inertness; and weatherability.

During the past 17 years, a pattern of blending new discovery with established principles has enabled the silicone chemist to maintain the basic nature of silicones, while introducing new properties and qualities required by specific applications. Through this pattern were evolved the one-part silicone rubber joint sealants.

CHARACTERISTICS AND PHYSICAL PROPERTIES

Basically, silicone rubber is available in a heat-vulcanizable form for extruded, coated, and molded shapes; a two-part, room temperature vulcanizing form for potting, casting, and some types of sealing; and the one-part, room temperature-curing silicone rubber for calking and sealing. Although potentially available in a variety of consistencies, the primary one-part silicone rubber joint sealant is a paste material which converts, on exposure to moisture in air, to a silicone rubber embodying the typical silicone characteristics.

A true rubber, the one-part silicone sealant chemically cures to a hardness of about 20 durometer points in less than seven days, by reacting with water in the surrounding atmosphere. It is tackfree in less than one hour, and attains a tensile strength of approximately 150 psi at an ultimate elongation of greater than 250%.

Like all good silicone rubbers, the one-part sealant resists weathering. Silicone rubber samples exposed in a flexed position on test racks for 12 years at a South Florida Test Station show little effect of age or environment. Similarly, one-part sealant samples on roof racks in Midland, Michigan, and at the same South Florida Test Station, show virtually no change in hardness or adhesion after over four years of aging. Weatherometer cycling for over 6,500 hours of pigmented and unpigmented sealant in both bead and film form show no change in color or loss of adhesion, and a hardness change of less than 10 durometer points.

Again like silicone rubber, the one-part silicone sealant remains flexible at temperatures from -85° F to 350° F, certainly well beyond the general environmental limits of buildings. But its performance over a wide temperature range extrapolates to a life of over 60 years at as high a temperature as 120° F.

The one-part silicone joint sealant is chemically inert, adheres well to a wide variety of construction materials, has excellent elastic memory, and will not bleed or stain. It is available in a variety of colors, including white, and there is even an unpigmented version.

JOINT DESIGN

Rarely is a product successful unless it is properly designed for and installed. Joint characteristics are, of course, important when considering the use of any sealant. Ideally, a joint should be designed for a particular sealing material, where possible. In any case, five important factors should be considered:

1. Cross-section of the bead
2. Movement of the joint
3. Accessibility of the joint
4. Compatibility of joint system
5. Possible physical abuse of the sealant.

These factors are closely inter-related; each influences the other and, at the same time, depends on the other. A joint that is properly designed achieves optimum performance by the proper balance of all these factors. Because of the stability of the one-part silicone rubber sealant over a wide range of environmental conditions, joints may be designed which rely on the elasticity, memory and adhesion of the sealant for performance. Original properties of the sealant need not be designed to compensate for expected changes due to aging, as significant changes do not occur.

Cross Section of the Bead

Because of the rubbery nature of the one-part silicone rubber sealant, the shape of bead is an important consideration in obtaining maximum performance, as well as optimum economy. Generally, there is considerable latitude in allowable bead size and, as with most bulk sealants, dimensional tolerances are not critical. Recommended ranges for width are 1/32 in. to 1 in. and for depth 1/32 in. to 3/8 in. Wider joints are feasible in certain instances.

Beads less than 1/32 in. deep do not offer sufficient bonding surface to insure proper sealing. Because the one-part silicone sealant cures on exposure to atmospheric moisture, beads deeper than 3/8 in. are slower to cure. More important than cure rate, however, is the fact that beads deeper than 3/8 in. present too great a sealant bulk for maximum performance, since it reduces the ability of the sealant to elongate and maintain a seal as the joint expands. The stresses developed in the sealant decrease as the depth decreases, thus allowing joints to be designed to give maximum performance, as well as optimum economy.

Stresses developed at the bonding surface also decrease as the joint shape approaches that of an ASTM tensile bar, i.e., concave on both upper and lower surfaces. Concavity of the upper surface can be obtained by tooling, while that of the lower surface can be obtained by using a round or semi-round back-up material.

Movement of the Joint

The silicone sealant is designed principally for sealing joints where expansion and contraction of up to 50% is anticipated. Properly applied, it should maintain adhesion throughout this range of expansion and contraction, even after years of aging. This sealant is also highly resistant to permanent deformation from compressive loads. A correct joint will have a width consistent with the physical limitations of the sealant.

Accessibility of the Joint

The joint should be accessible enough to be sealed by conventional equipment, and should also be wide enough to insure proper cleaning, good wetting, and adequate surface contact for adhesion.

Compatibility of the Joint System

The joint system consists of the joint materials or substrates, the sealant, the back-up materials, the fasteners, and the joint design or shape. Compatibility of the system as a whole is important.

The silicone sealant is compatible with a wide variety of building materials, although asphaltic materials, impregnated wood, and other materials which may bleed oils or solvents are not suitable substrates.

Back-up materials suitable for use with the sealant include glass fibers or mat, building paper, untreated jute, expanded polystyrene, polyethylene and urethane foams, cured mortar, polyvinyl chloride, most polybutylenes, and metal foil. As with the substrates, materials that tend to bleed oils or solvents should be avoided. These include asphalt or pitch, oakum, and oil-impregnated fibers. If the building sealant is to come into contact with rubber tapes or gaskets, they should be specified as nonstraining. This is especially important in the use of light-colored sealants, since rubbers, such as the neoprenes and butyls, contain antioxidants which migrate to the surface and discolor on exposure to ultra-violet rays.

Choice of fasteners can also be important. Care must be taken not to set up a galvanic cell by use of dissimilar metals in a joint.

Possible Physical Abuse of the Sealant

The anticipated physical abuse of the sealant should be taken into account when specifying the sealant thickness. If the surface of the sealant will be subjected to abrasion, picking, foot traffic, or other physical wear, the thickness of the sealant should be increased accordingly.

APPLICATION CHARACTERISTICS

Not too many years ago, architects, contractors, and owners had little real concern about the methods for applying sealing compounds. The advent of two-part elastomeric sealants, with accompanying problems of mixing, storage, and application, increased everyone's concern for proper sealant installation. The one-part silicone rubber sealant overcomes many of the commonly encountered job-site problems.

First, there are the obvious advantages of a one-part sealant. Delivered to the job-site ready to use, these materials require no mixing, thus minimizing waste and eliminating both a labor step and the possibility of faulty mixing. There is no work-life problem. The applicator can set his gun aside, go on a coffee break, and afterward return to calking without delay. If he stays for a second cup, a plug may form in the end of the nozzle, but this is easily removed, and the gun is ready to go again.

Second, the one-part silicone rubber sealant is available in a variety of convenient packages. There are bulk packages for use in bulk guns or with pumps, and polyethylene cartridges suitable for use with standard pressure equipment or adaptable to hand guns. The applicator can choose between a variety of both standard and nonstandard types of equipment, depending on which suits his job best.

Third, the silicone sealant is easy to clean from one's hands and equipment. It is of such a consistency that it is not tiring to apply from a hand gun, yet it will not slump or sag in vertical joints. In fact, a basic stability over a wide range of environmental conditions is common to both the compound before it cures and to the cured product. It can be applied year-round, and handles as easily at high or at freezing temperatures, curing at either extreme.

Field applications have been made over a temperature range of 0° to 120° F. with no evidence of a change in product consistency. Although relative humidity affects the rate of cure to some extent, cure will take place at a relative humidity as low as 5%. The cure rate will depend on the bead size and the ratio of exposed surface area to depth.

Fourth, the sealant can be stored on the job-site without refrigeration. Storage temperatures below 90° F are recommended.

Although the sealant is simple to handle, its performance depends in large part on the condition of the surfaces to which it is applied. It adheres well to a wide variety of construction materials such as glass, aluminum, steel, ceramics, masonry, porcelain enamel, and some plastics. There are no miracles here, however, as surfaces must be clean. Generally a surface conditioner should be applied, to enhance adhesion and insure more consistent results. On masonry in particular, this cleaner-primer is recommended, not as a stain barrier but as a surface conditioner.

FIELD EXPERIENCE

Designed first as a sealant for modern curtain wall construction, the one-part silicone rubber sealant has found many additional uses, both as a sealant and an adhesive. It has proved economical in shop application, as well as for job-site use.

A large number of installations of various types have been made since the first application in 1958. Sites were chosen so as to encounter a representative sample of the possible combinations of building materials in both new and remedial work.

One of the more interesting remedial applications was the sealing of the S. C. Johnson and Sons building complex in Racine, Wisconsin. Prominent in this group of buildings, designed by Frank Lloyd Wright, is the 154 ft. Research Tower, believed to be the tallest cantilevered structure in existence (Figure 1). This building has over 133,000 ft. of glass tubing requiring sealing. The sealant was used in several small, critical areas during 1958. Work on completely sealing the Tower was started in the summer of 1959. Because of the quantity of material required, the sealant was applied from six-gallon pails with a pump, and pumped directly into the glass-to-glass joints (Figure 2). The excellent adhesion demonstrated in sealing the glass tubes has since led to the use of the silicone sealant in sealing masonry copings, copper flashings, and polyester laminated skylights.

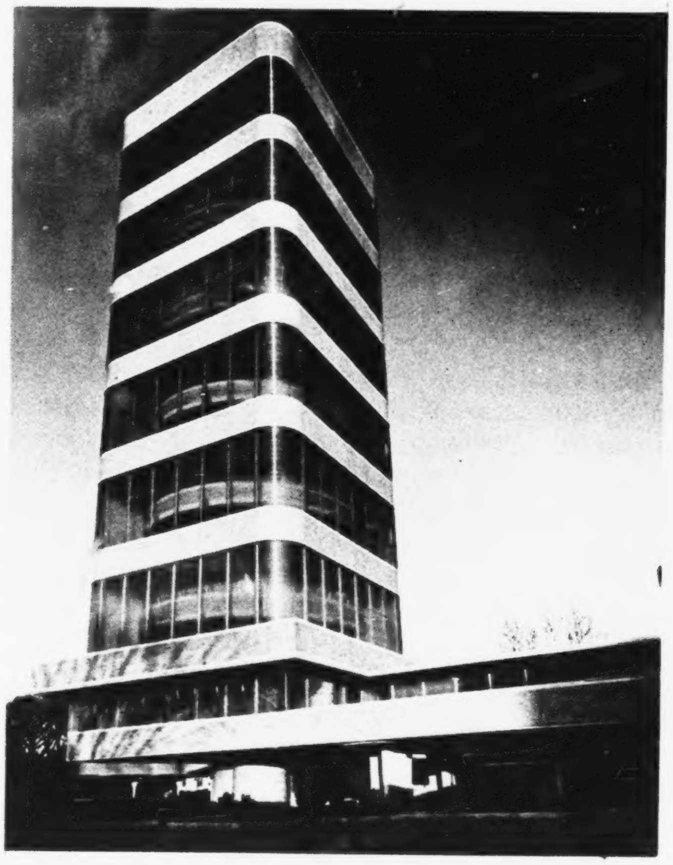

Figure 1 -- Over 133,000 feet of glass tubing in this 154 foot tower require sealing.

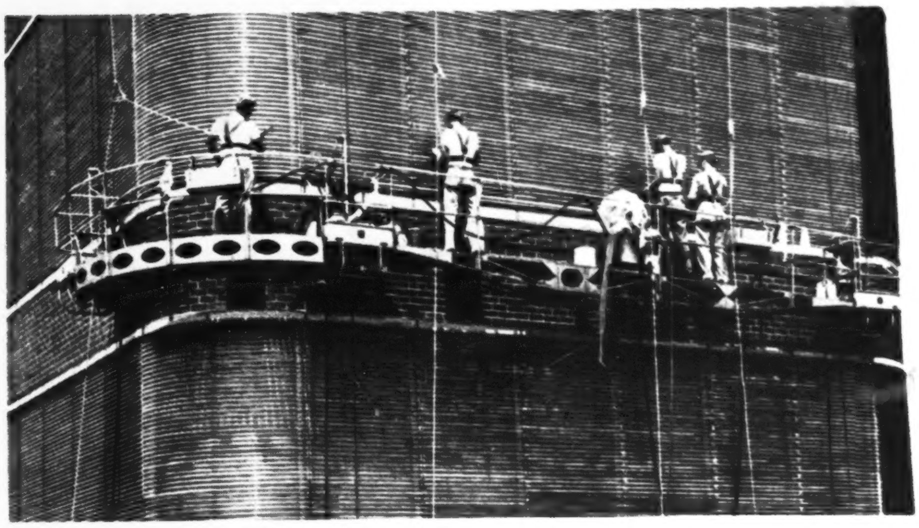

Figure 2--Sealant is pumped directly into glass-to-glass joints.

Examples of other large-scale field applications are the Florida National Bank in Jacksonville, Florida, where the sealant was used to seal the limestone to the aluminum sash, and the metal panel-wall system used in the Broadway School, Elmira, New York. More recently the sealant has been used to seal the mosaic panels of the Michigan Consolidated Gas Company building in Detroit, Michigan, and the marble-to-steel sash of the United Insurance Company of America building in Chicago, Illinois.

The silicone rubber joint sealant has been used in glazing applicautions, primarily in exposed beads or water stops. It has also been used to grout and seal ceramic tile, and boasts a long list of satisfied do-it-yourself bathtub calkers.

ADVANTAGES AND LIMITATIONS

In spite of a relatively high initial material cost, the silicone sealant has proven economical due to lower application costs, quality performance, long life, and low maintenance.

A time and labor saver, the silicone sealant is faster to apply, easier to clean up, and affords minimum waste. Its low maintenance is a direct result of quality performance and long life. Among its advantages one must list its aesthetic values. Available in a wide variety of colors, it does not sag or run on a vertical surface, is nonstaining, will not craze or crack, and does not bleed. Because of its rubberiness and elastic memory (lack of cold flow), it can be designed for smaller cross-sections.

Its limitations are typical of those of a high-performance, rubbery sealant which depends on adhesion and cohesive strength for its sealant characteristics. Joint substrates must be clean, and the material must be properly applied so that it is in position to seal adjacent surfaces. It should not be used over asphalt, pitch or other materials which tend to bleed oils or solvents, as they will diffuse through the material and destroy the bond. Back-up materials should be chosen carefully, to maintain the full aesthetic value of the sealant.

Like all rubbery materials, when painted it is difficult to maintain film integrity of the resinous paint over the rubbery substrates, as the rubber flexes with the movement of the joint.

Thus, with experience over the past 17 years setting the stage, a one-part silicone rubber high performance building sealant has been developed, which minimizes waste and labor problems, while adding to the functional as well as to the aesthetic qualities of a building. Field experience demonstrating the practical aspects of application and performance has been successful. A new product is ready for the building industry.

Chlorosulfonated Polyethylene Sealing Compounds

By Edward O. Hilbush, Jr., West Chester Chemical Company

Abstract: This paper describes the development of a sealing compound based on chlorosulfonated polyethylene, a new elastomeric polymer selected as having ideal properties for a sealant. Chlorosulfonated polyethylene has high resistance to ozone, ultra-violet rays, and weathering over a wide range of temperatures. It is also highly resistant to chemicals, tough yet flexible, and has good adhesion, and color stability.

THIS PAPER COVERS WHAT HAS BEEN ACCOMPLISHED recently with chlorosulfonated poyethylene, one of the most promising new materials for the building industry, in a sort of interim report.

As construction men well know, whenever two pieces of material are put together, there is a potential problem. This is true regardless of the kind of construction, the craft, or the material. It is true in light and heavy building construction, shipbuilding, the automotive industry, and aircraft and railway manufacture. It is even found in the appliance and electronic industries. The problem has to be faced by all tradesmen, whether the materials be wood, brick, steel, aluminum, plastic, glass, alloys, or fabric.

The field of joint sealing is indeed broad, and one in which our company has had a natural interest. We pioneered the development and application of elastomeric coatings for roofing on buildings of modern design. This type of design, more often than not, involves unusual substrates and geometry. It also means unusual joint-sealing problems. Thus, we turned our efforts to finding solutions to these problems. And, quite naturally, the materials with which we worked were elastomers, for two reasons:

1. They were the materials with which we were most familiar.
2. They were the materials which had the properties most likely to offer the right answers.

HILBUSH, EDWARD O., JR. President, West Chester Chemical Company; member, BRI, Society for the Advancement of Management.

EARLY DEVELOPMENT

In 1958, we decided to add a new and superior elastomeric sealant to our line, to fill the need in modern building construction. We were looking for an ideal sealing material, one which would have the following properties:

1. Tight adhesion
2. Good elongation and resilience
3. Resistance to discoloration and degradation under severe weather
4. Good chemical resistance
5. No corrosive effect on metal and no ingredients to stain metal and marble
6. Ease of application with conventional equipment
7. Absence of on-the-job mixing
8. Long shelf-life in the container
9. Lack of slump or sag
10. High solids and low shrinkage
11. Quick set and tackfree surface
12. Unlimited range of colors to match or contrast with modern decors
13. Adequate performance under a wide range of temperatures, i.e., flexibility at sub-zero temperatures and absence of softening or slump at high temperatures
14. Low cost

These properties have been mentioned in no particular order, nor are they by any means all of the desirable characteristics, but they were our major considerations. We felt that a sealing material should maintain all of these properties indefinitely, and withstand continual expansion and contraction without failure. Further, with the rapid changes or building alterations which are frequently encountered, it should be easily repairable if damaged by severe external mechanical forces.

PHYSICAL PROPERTIES

After looking at the many elastomeric materials which seemed to have suitable properties, we chose one of the very new ones, chlorosulfonated polyethylene. This polymer was selected because it seemed to have the greatest number of desirable properties for an ideal sealant. For example, the basic polymer is ozone-resistant, and has been used in gaskets on ozone generators. It has superior weather resistance, as demonstrated by the fact that it is now being used in white sidewall tires to resist cracking. In 1959, it was well on the way to proving itself as a roof-coating material, and was standing up very well, even in the tropics.

Its broad chemical resistance had been proven, since it was being used for acid hoses, tank linings, etc. Its heat resistance was proven;

it was being used in conveyor belts to handle salt at 325° F. Its abrasion resistance was demonstrated; shoe soles and heels made with chlorosulfonated polyethylene were wearing two to four times as long as other materials. Its color stability I proved to my own satisfaction. Every member of our organization has used coatings based on chlorosulfonated polyethylene to paint his home. In fact, even the the office building is painted with this material.

Chlorosulfonated polyethylene was developed in the early 1950's to fill a need for an elastomeric material with extremely high resistance to ozone, ultra-violet rays, and weathering over a wide range of temperatures. In addition, it is highly resistant to chemicals, particularly strong oxidizing acids. It is serviceable at temperatures ranging from -40° F to 250° F. Physically, the raw polymer is an elastomeric solid which has a durometer value of 55 to 95. When properly compounded, we have found it to be a very tough, yet flexible, sealing compound.

In developing this sealant, it was discovered, as you might imagine, that not even this polymer fulfilled every requirement. As with most products in the field, some compromise is necessary. The goal was to get the best possible balance between all of the desirable characteristics. It was necessary to strike a practical compromise among opposing characteristics, such as high solids and low shrinkage on one hand, and gunability and ease of application on the other.

NEED FOR ONE-PART MATERIAL

Because of the inconvenience and the frequently inconsistent results experienced with two-part systems, we were convinced of the absolute necessity of making this sealant a one-part material. This would not only offer ease of application on the job, but would also permit more positive control of the rate of cure, thus assuring more consistent results. Of course, a one-package material and good cure rate posed a problem -- shelf-life. This was one of the most serious problems encountered, and the earliest formulations often lasted no longer than two weeks. Intense research on the problem has resulted in continual improvement. When three months' shelf-life was experienced, it was considered that the product was ready for limited commercialization.

The shelf-life problem is a difficult one, because a cure rate is not selective. If the sealant is compounded to cure rapidly on the job, it also tends to cure too rapidly in the can or tube. If you retard the cure long enough for long can or tube stability, the surface of the sealant, when extruded, remains tacky for too long a period and has a tendency to collect dust and dirt. At present, the product is stable for six to eight months, yet cures fast enough to avoid trouble with dust and dirt. The goal is a shelf-life of 18 months to two years, so you can see there is still much work to be done.

The high solids content of the sealant, and the natural drag of the rubber polymer, tend to make the compounded sealant more difficult to gun than conventional oil or clay-filler types. Despite this, we have not found its gunability significantly objectionable, particularly when the sealant is installed by professionals. If the material is warmed slightly by storing at about 150° F for one hour in a heated area, immediately before using, there is a significant improvement in its gunability.

PRESENT-DAY PERFORMANCE CHARACTERISTICS

While there have been headaches, let's now review the outstanding properties of the sealant as manufactured today. The adhesion characteristics are quite good, and range from approximately 25 psi for marble to an average of 60 psi for aluminum. The range of adhesion for all common construction materials appears to be more than adequate. The general rule for good adhesion is that the bonding surfaces must be clean. This condition is essential with chlorosulfonated polyethylene-based sealants as indeed, with all sealants. However, unlike some of the other synthetic rubbers, it is not necessary to apply a primer for good adhesion.

The sag or flow characteristics are good, even in a vertical joint at 122° F. The temperature range in service, -40° F to 250° F, certainly covers a sufficiently broad range. Because you can maintain high solids, there is only a 2% to 5% shrinkage. The actual amount of shrinkage will depend upon the conditions under which the solvent evaporates from the surface.

Initially, a skin is formed and the final product, after evaporation of all of the solvents through this skin, will exhibit some slight shrinkage (of the surface) together with a cellular type of body. This does not imply cells of the type normally thought of in sponge or foam, but rather cells of a microscopic nature. Thus, the full shrinkage, equivalent to the volume of lost solvent, is not realized. These cells are closed, very small, and non-communicating, and therefore, do not affect the water resistance of the cured product. An important fact which should be stated here is that because of the slow rate of cure, the shrinkage of the sealant does not set up stresses in the rubber. The sealant finally reaches full cure after shrinkage has occurred.

The sealant now compounded is compatible with most building materials, even asphaltics. In the case of asphaltics, for example, you will experience some bleed-through which could be unsightly if light or pastel finishes were desired. Tests run to date have shown that this bleed-through has caused no effects detrimental to the cured sealant. Under these conditions, it is recommended that a gray or black sealant be used to avoid the risk of discoloration. As with most of the other synthetic, rubber-like compounds, best results are obtained if the back-up materials are of the type that do not bleed oils or solvents. Of course, the best back-up materials would be untreated jute, rock wool, glass fibers, urethane foams, etc.

The range of elongation of the chlorosulfonated polyethylene weathered sealant is 95% to 100%. The sealant is nonstaining and noncorrosive, and offers resistance to migration of solvents and plasticizers. The sealant is self-extinguishing when cured, can be manufactured in a complete range of colors, and has excellent weathering characteristics. In fact, we have never been able to measure erosion on the sealant with the weatherometer, even after 3,000 hours.

Chlorosulfonated polyethylene-based compounds have been exposed to sunlight for years, and artificially aged under sunlamps for equivalent lengths of time without failure. One comparison test in an ozone atmosphere showed a natural rubber sample cracking in 13 minutes, while the new polymer was unaffected after exposure for 100 hours. In this case, the ozone content was 100 PPM, which is far greater than the normal atmospheric concentration of 1/2 of one part per million. Since erosion rates are important, we have, through weathering tests, determined that the maximum rate of erosion, even under severe conditions, would never be more than 1/2 mil per year. The average erosion rate experienced to date is approximately 2/10 mil per year, which can be extrapolated to the conclusion that this compound used in a building joint will endure for the life of the building.

Because of the need for chlorosulfonated polyethylene-based sealants to lose solvent before full cure occurs, the rate of cure is slow and, of course, dependent upon the ambient conditions. Figure 1 shows a development of cure properties over a period of five months. The physical properties, in this case, are conveniently followed by measuring the increase of hardness which is indicative of the rate of cure. The spread shown here is the result of extreme ambient conditions; for example, 100° F to 120° F coupled with low relative humidities will produce a Shore hardness of approximately 31 after 15 weeks' exposure.

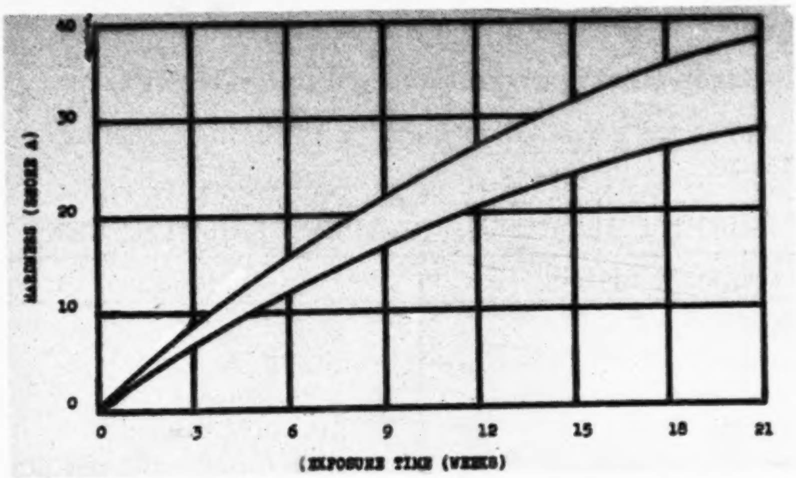

Figure 1 -- Rate of hardening of chlorosulfonated polyethylene on exposure.

COMPARATIVE PERFORMANCE TEST

Five samples of different types of sealants were exposed for 18 months at south 45° on the east coast. The materials used for retention were wood blocks with 1/2 in. x 1/2 in. channel and 1 in. aluminum channel x 3/8 in. deep. A piece of glass was imbedded in the sealant in the aluminum channel. The bottom portion of the wood was painted to check for staining.

The first sample was a common drying-oil, clay-filler type of sealant. The sample cracked. An acrylic-based sealant was used in the second sample. The slump was noticeable and there was also some evidence of cracking. A polyurethane-based sealant swelled and had poor adhesion on aluminum. The polysulfide sealant performed well, with the exception of its paint-staining characteristics. The fourth sample, with the chlorosulfonated polyethylene sealant as it is manufactured today, showed an absence of paint-staining, cracking, or swelling.

CHARACTERISTICS

Characteristics for this new chlorosulfonated polyethylene sealant include:

1. Excellent weatherability
2. Unlimited colorability -- color stability
3. Non-corrosion
4. Non-staining
5. Negligible migration of solvents and plasticizers
6. Good adhesion to most building materials
7. Negligible slump (test 3 hr. at 122° F)
8. Shrinkage (60 days at room temperature) -- 2%-5%
9. Tackfree time at room temperature -- 36-48 hr.

Table 1 shows the physical properties of the new sealant.

TABLE 1 -- PHYSICAL PROPERTIES OF CURED CHLOROSULFONATED POLYETHYLENE

Property tested	Result
Solids	90%
Hardness	15-25 shore A
Tensile strength	100-175 psi
Elongation	50-100%
Flame resistance	Cured calk will not support combustion.
Temperature range	-40° F. to 250° F.

APPLICATIONS

The proof of any product is, of course, in its successful application. In one of the semi-custom homes built by the J. F. Blackman Company in Brinton Lea, near West Chester, Pa., the sealant was used successfully at the intersection of aluminum siding and masonry and to seal the aluminum to wood window frame joints. At the Sciota Downs Harness Race Track outside of Columbus, Ohio, the chlorosulfonated polyethylene sealant was used at the ridges and valleys of folded plate roofs.

It has also been used for marble office-entrance steps. After a year's service, it did not show any separation or lack of adhesion.

The chlorosulfonated polyethylene sealant was also used in a 3/4 in. x 3/4 in. construction joint in our own plant. A new wing was added last fall, and the backing strip was asphalt. We want to see just how much bleed-through will be experienced in this type of service.

On the roof of the Avocado School, Dade County, Florida, plastic skylights have been set in the chlorosulfonated polyethylene sealant. In the application, the skylights were then nailed to the precast concrete roof.

Another application was a wall to sidewalk joint, which was originally sealed with a hot asphalt that had to be repaired with almost every change of season. Installation of electronic equipment in the basement made it important to stop the leaks. In this case, all the contractor did was to cut out slightly at the asphalt cracks and fill with the chlorosulfonated polyethylene sealant.

The sealant has also been used on concrete stave silos at both the bottom and top horizontal joints, as well as at all pipe openings. This is a rather critical job, in that no moisture can be tolerated.

Another interesting application of the sealant was made in a country home just outside of West Chester, Pa. I include this example because the construction of this home was rather unusual. This is a case in which the roof was built first. The earth was mounded and compacted on the side of a hill in the shape desired for the finished roof. The ground was then covered with asphaltic paper, the edges were formed to provide the thicknesses required, and the concrete roof was poured over them. The ground was excavated from under the roof and the house built beneath it. The sealant was used at the roof curb joint. It blended in with the white chlorosulfonated polyethylene coating used to provide water and weather protection for the poured slab.

As can be seen from the above examples, the material has been used in many different types of applications. It has also been used to seal a 30-foot planked boat for more than two years. The planks, sealed above and below the water line, have withstood the swelling and shrinkage that occurs every spring and fall, and the owner advises us that this is the finest type of sealing compound he has ever used on a boat. Swimming pool owners have likewise advised that it is performing well in both cracks and expansion joints after three years of service. This type of on-the-job success in difficult applications is, we feel, an excellent recommendation for chlorosulfonated polyethylene sealants.

Polyurethane Joint Sealants

By Charles M. Fosgate, Jr., United Shoe Machinery Corporation

Abstract: There are two basic types of polyurethane sealants--polyester and polyether. The polyester-based urethane sealant has the ultimate in physical properties available from urethanes but its cohesive strength is too great for general acceptance as a sealant. The polyether-based urethane sealant has greater stretch, is lower in cost, and is not susceptible to attack by water. Polyurethanes must have tackifiers compounded in, but this can be done chemically with no staining or hardening and there is no need for a primer. Typical performance data, tests, advantages, limitations, and application are discussed.

POLYURETHANE, FIVE YEARS AGO, was little more than a hard-to-pronounce name. Today it is a hard, impact- and abrasion-resistant, rigid rubber for machine gears; an elastic, impact- and abrasion-resistant rubber for durable truck tires; a hard, weatherable, abrasion- and impact-resistant marine finish; an extremely durable, corrosion-resistant finish for industry; a rigid, shock-resistant foam for safely packaging the Navy's new missile torpedos; a soft, comfortable foam cushioning for upholstery; a rigid foam core for curtain wall panels; and now, a high performance, weather-resistant sealant.

Since the last Building Research Institute Conference on Sealants for Curtain Walls in 1959, major strides have been made in the development of polyurethane sealants. The word, "polyurethane," however, may be somewhat misleading; for, within this broad chemical classification, there is an almost infinite variety of polymers and subsequent compounds which can be developed.

Many of us within the field of urethane chemistry are proceeding in vastly different directions to achieve the same end results. Note that I say results, or performance, rather than identifying a particular compound, for the approaches to the solution of a given problem are limited only by the imagination of those working on the problem. With this thought in mind, this paper will attempt to describe a typical approach to the polyurethane sealant question, our solution, and the resultant advantages and limitations that may be derived from these compounds. I must first dwell briefly on the technical aspects of the material itself, because this will assist you in your future selection of a proper material within the polyurethane family.

FOSGATE, CHARLES M., JR. Manager, Product Development, B. B. Chemical Division, United Shoe Machinery Corporation.

TECHNICAL ASPECTS OF THE MATERIAL

Two basic types of polyurethane compounds may be found under development by the various sealant manufacturers: polyester and polyether. To develop a urethane from the polyester family, we partially react a hydroxyl-terminated polyester with an isocyanate, to produce a urethane prepolymer. This prepolymer is compounded and reacted with various ingredients to develop the part "A" of the polyurethane sealant, much as latex is compounded to develop suitable rubbers. Just prior to use by the contractor, it is mixed with a catalytic bridging agent, part "B," which causes the individual prepolymer molecules to link and cross-link, like snarled tire chains. The result is a rubbery material with characteristic sealant properties.

Essentially, the same procedure is followed to produce a polyurethane sealant derived from the polyether family, except that a hydroxyl-terminated polyether is substituted for the polyester.

Now, what is the difference between these two materials -- the polyester- and the polyether-based urethane sealants? Essentially, the polyester provides us with the ultimate in physical properties available from urethanes. Its toughness, tensile strength, abrasion resistance, and general strength are primarily due to two factors, high cross-linking density, and high secondary valence forces, i.e., "magnetic" attraction of the molecules. In fact, this magnetic force is almost as strong as the actual chain linkages. While these two factors account for its excellent sealant characteristics, they also prohibit its general acceptance as a sealant, because the cohesive strength of the material is so great. Even by proper compounding, it is extremely difficult to reduce the cohesive factors to a point where elongation or "stretch" of the material can be obtained with minimum applied force.

These high secondary, or magnetic, forces are normally found in very polar materials, i.e., a material with a high number of chemical groupings similar to that found in water. The polyethers are less polar than the polyesters, and their secondary bonding forces are therefore weaker. With the reduced cohesive strength found in the polyether-based polyurethanes, elongation is obtained with less applied force, and fewer stresses are therefore obtained in the joint. In a good sealant, we feel 150% elongation should be reached with a force greater than 10 lb. per sq. in., but less than 60 lb.

What differences between the two are there in other respects? Generally speaking, the integrity of a polyester-based polyurethane is better than that of a polyether. There is little, if any, evidence of surface crazing in the polyesters, whereas this is slightly apparent in both polyether-based urethanes and the polysulfides, with which you are more familiar. The color stability of the polyester type is better than that of the polyether, but the polyether is adequate in this respect.

On the other hand, the polyether-based polyurethane can be developed with greater stretch, is not susceptible to slow hydrolysis, i.e., attack by water, and is lower in cost. The raw material cost differential between the polyester and the polyether is two to one, and that of the finished compound is one and one-half to one. That is, the polyester-based sealant will generally be half again more expensive.

RECENT DEVELOPMENTS

At the 1959 BRI session, we were told that, as of that time, the industry had not been able to develop sufficient adhesion in the polyurethane sealants, and that to secure this adhesion, most surfaces had first to be primed, a costly and time-consuming operation. Although we have found generally better adhesive properties among the polyether class of urethane sealants, the adhesion of the basic polymers is not sufficient for proper performance. Nor, in fact, is it sufficient in an uncompounded polysulfide.

External ingredients, or tackifiers, are usually compounded into the polysulfides and the polyurethanes to produce the necessary adhesion. It was these tackifiers that caused the staining problem over marble and concrete, so noticeable in the earlier days of the polysulfides. They migrated to the surface and were absorbed by the surrounding substrate. Over long-term exposure, the loss of these tackifiers presented an additional problem, for the sealant would become progressively harder, tensile would increase, and ultimate elongation would decrease.

As in the polysulfides, the polyurethanes must have tackifiers added, but there has been developed a means of internally tackifying the resin systems, that is, chemically attaching the tackifying agent to the basic molecule of the polyurethane resin. The tackifiers will not, therefore, migrate to the surface, or be lost by the erosion of weather. There is no staining problem, and no subsequent hardening of the sealant from loss of a critical ingredient. Adhesion to a wide range of substrates, without the necessity of a primer, is now possible.

In any comparative discussion, we must choose a point of departure. The polysulfides are a suitable choice in this respect, for their performance characteristics are well known and proven. Table 1 presents an evaluation under the standard procedures for evaluating polysulfides, approved July 27, 1960, by the American Standards Association.

ADVANTAGES

Cost: Polyether-derived polyurethane sealants are available in a competitive price range of $12-17 per gallon unit.

Adhesion: Excellent to glass, metal, wood, and masonry surfaces. No primers are necessary, but it is recommended that masonry be primed solely to densify a possibly dusty surface.

TABLE 1 -- POLYURETHANE SEALANT -- TYPICAL PERFORMANCE DATA

Property Tested	ASA Test Method[1]	Polyurethane Sealant	
		Black	Gray
Hardness (Shore A)		25-35	25-35
Tensile at 150% elongation	7.4.4	60-100 psi	50- 80 psi
Ultimate tensile	7.4.4	200-225 psi	225-250 psi
Ultimate elongation[2]	7.4.4	200-225 psi	300-325%
Low temperature elongation[3]	7.4.4.4		
@ - 20° F.		150+%	150+%
@ -106° F.		150+%	105%
High temperature performance[4]	7.4.4.3		
Standard Specification		conforms	conforms
2 hr. @325° F.[5] - tensile		250+psi	220 psi
-elongation		175%	225%
Sag characteristics	7.3	nil	nil
Crazing (depth)	6.5	less than 3 mil.	less than 3 mil.
Recovery[6]	6.4	90+%	90+%
Pot Life (hr. at 77° F.)	7.1	20 hr.	20 hr.
(hr. at 100° F.)		12 hr.	12 hr.
(hr. at 120° F.)		5 hr.	5 hr.
Application temperature		40-130° F.	40-130° F.
Specific gravity		1.11	1.125

[1] Test methods adopted from American Standard Specification for Polysulfide-Base Sealing Compounds for the Building Trade, ASA 116.1-1960.

[2] Ultimate tensile and elongation conducted on samples aged two months. Low temperature elongation, high temperature performance, and recovery, conducted on samples aged two weeks. Standard specification for polysulfide requires tests to be conducted on sample aged seven days. Polyurethane, however, requires longer conditioning periods to reach ultimate properties.

[3] Standard specifications require minimum of 100% at -20° F. Urethanes far exceed this.

[4] Standard specification requires minimum of 100% extension at a minimum force of 10 psi following 24 hr. exposure to 158° F. Urethanes conform.

[5] Polysulfide shows evidence of decomposition following 2 hr. exposure at 325° F.

[6] Standard specifications require minimum of 25% recovery within one hr. following sample extension to 150% for a period of 5 min. at 77° F.

Staining: None.

Tensile Strength: The ultimate tensile strength is approximately twice that of the average polysulfide, yet the force required to extend to 150% elongation is approximately the same. Hence, it provides a stronger material with no greater stress on the joint system.

Performance Under Temperature Extremes: Excellent -- the black urethane has greater than 150% elongation at -106° F. and the grey, 105%. Polyurethanes conform to the ASA test requirements after 24 hr. exposure to 158 °F. and retained a high percentage of their original tensile and elongation after two hr. at 325° F.

Recovery: The polyurethanes have a remarkable resilience, or ability to return to the original dimension following deformation. Whereas the ASA Standard calls for a minimum return of 25%, the urethanes have a minimum of approximately 90%.

Pot Life: An extended pot life of up to 20 hours at 77° F, and 12 hours at 100° F is one of the most striking advantages of the polyurethanes. This allows premixing of a full day's requirements, and pressure feeding of the sealant into the application gun, with all the attendant advantages possible on a large application.

Weathering: All accelerated tests, together with actual field installations, indicate performance reliability in the range attained by the polysulfides. Resistance to ozone and oxygen are excellent. Adhesion to glass following ultra-violet ray exposure is very good.

Fluid Resistance:

	Polysulfide	Polyurethanes
Water	Excellent	Excellent
Jet fluid (JP-4)	Excellent	Excellent
Diester oil	Fair	Good
Hydrocarbon oil	Outstanding	Outstanding
Non-inflammable aircraft hydraulic fluid	Poor to fair	Fair to good
Liquid oxygen	Poor to fair	Good to excellent
Kerosene	Outstanding	Outstanding
Ketones	Fair	Good

LIMITATIONS

Moisture Sensitivity: This is evident only in the uncured state. Polyurethane sealants, during manufacture, packaging and application, must be kept rigorously free from moisture contamination. Application to a wet or damp joint will cause foaming or swelling of the material, with subsequent detrimental effect upon its performance characteristics.

Color Degradation: On exposure to ultra-violet light, the material shows a tendency towards bronzing. This is purely an aesthetic and temporary problem with color returning to approximately the original within nine to 12 months.

Toxicity: During mixing operations, the polyurethane curing agent may irritate a sensitive person's skin. It is therefore recommended that suitable gloves be worn. The fact that an isocyanate is used in the manufacture of polyurethanes leads many to assume that the material is as toxic as cyanide. This is false. The isocyanate as such, is a lachrymator, that is, it has much the same effect as tear gas upon the mucous membrane. If it were present in any great quantity in a free state, it could be seriously irritating to the applicator. However, the majority of the isocyanate is prereacted with the resin involved, with only a very minute amount remaining in the compound in the free state. In the five years that we have been preparing polyurethane compounds of various types, there have been no injuries which could be attributed to the isocyanate in the system.

Once parts "A" and "B" have been reacted, we feel that the system is quite innocuous. Certain types of polyurethane coatings have been approved by the U.S. Pure Food and Drug Administration for use in coating the interiors of transportation vehicles, which are used in the transportation of dry bulk foods. The U.S. Army Quartermaster Corps, at its facility in Amarillo, Texas, has coated the interior of a 250,000-gallon concrete water tank with a polyurethane coating, to protect the concrete from the corrosive effects of the drinking water.

Curing Time: It has often been said that we cannot have our cake and eat it, too. This holds equally true for the polyurethanes. Where we have been able to provide exceptionally long pot life, we must pay the penalty in the form of a somewhat longer curing time than is common in the polysulfides. Hence, where the polysulfides reach maximum cure under normal conditions within seven days, the polyurethanes require 14 days. This presents no problem in normal construction, for the material skins over within 24-30 hours. This long curing period would, however present a problem, were we to use polyurethanes in the expansion joints of highways, which must be subjected to traffic within a day or two of application. Special compounds of short pot life, applied by special equipment, can be readily developed for this use.

APPLICATION

The polyurethane sealants are not difficult to mix or apply. As a rule of thumb, we might say that the handling properties are quite similar to those of the polysulfides. The material comes in one-gallon or five-gallon units, where the two components, parts "A" and "B," are accurately premeasured at the factory. There is sufficient head space left in the top of the one-gallon or five-gallon part "A" container to receive the full amount of part "B," and allow for mixing without spillage. The ratio of part "A" to part "B" is approximately three to one which, in a heavy viscosity material such as this, makes for more uniform mixing of the ingredients than in systems having mixing ratios of 10:1 or more, where only a small amount of part "B" is available for thorough distribution within the part "A." Mixing is best accomplished by power-driven tools, although careful hand mixing with a large spatula is adequate.

Application to the joint may be made with conventional hand calking guns, or with more refined equipment, where the sealant is fed to the gun from a pressure reservoir. A full day's supply may be mixed in the morning, without the necessity of freezing to extend the pot life. Many conventional solvents may be used for cleansing the applicator's tools while the material is in the uncured state. Should the material have cured, it can be removed by knife or burning.

Overnight soaking in a chlorinated solvent will soften the material somewhat for more easy removal, but there is no commonly available solvent which will readily dissolve the cured material.

Needless to say, the same standards of surface preparation prevail as set forth for the use of polysulfides. The adhesion of the polyurethane sealants is only as good as the surfaces to which they are applied, and these surfaces must be clean and dry. Clean and dry -- a short phrase, but a most important one.

SUMMARY

Although they are relatively new, and have yet to face the trial of time, polyurethanes have taken a long step forward during the past several years. Many of the problems outlined at the BRI Conference in 1959 have been overcome, and a remarkable new tool is now available to the construction industry. We are confident that in the coming years equally large strides will be taken to provide even better sealing materials.

As mentioned earlier, the future products of polyurethane chemistry are limited only by the imagination of those working with the materials: the architect, engineer, fabricator, contractor, and manufacturer.

Butyl Sealing Compounds

By W. P. Fitzgerald, Enjay Chemical Company

Abstract: A wide variety of sealants based on butyl rubber or polyisobutylene are available. These synthetic rubber materials are permanently elastic, with almost identical physical properties. Polyisobutylenes differ from butyl rubber in that they are produced over a wider range of molecular weights and are essentially free of double bonds in the polymer chain. Considerations for compounding, performance characteristics, and advantages and limitations of each type are discussed. Butyl sealing compounds are in the form of bulk sealants, ribbons, tapes, and composite systems. Butyl rubber is now available in latex form. A new elastomer—ethylene-propylene rubber—is unexcelled in resistance to weather, oxidation, ozone, and age.

BECAUSE OF THE RAPID GROWTH in recent years of the building industry in general, and curtain wall construction in particular, raw material suppliers and sealant manufacturers have spent much cooperative effort in developing a host of new, durable, and economical sealing compounds. Butyl rubber and polyisobutylene have been used increasingly in these sealants, because their inherent physical characteristics meet the demanding requirements of components for this type of construction.

Today, a wide variety of sealants based on butyl rubber or polyisobutylene are available. These include permanently flexible, one-part, nonskinning bulk compounds, bedding tapes, and composite, preformed, resilient sealing and glazing systems. In addition to these, new sealants with properties engineered for a wide range of applications are constantly being developed in the laboratories.

Butyl rubber and the polyisobutylenes comprise a family of synthetic rubber materials that are permanently elastic. Their performance and their ability to meet service requirements put them in a position between the oil-base sealing and glazing compounds and the two-part, self-curing systems. As we shall presently see, butyl rubber and polyisobutylene are quite similar, structurally. Their physical properties, except for some minor variations due to physical consistency, are almost identical.

It might be interesting to see what the butyl rubber structure looks like, and to relate this structure to its physical properties and performance characteristics.

FITZGERALD, W. P. Technical Service Coordinator, Synthetic Rubber Division, Enjay Chemical Company; member, American Chemical Society, ASTM, BRI.

STRUCTURE AS RELATED TO PROPERTIES AND PERFORMANCE

The butyl rubber molecule, as can be seen from the simplified schematic diagram in Figure 1, is essentially a chain of saturated hydrocarbon. The carbon-hydrogen chain is relatively long and straight and between 47,000 and 60,000 links or units are strung together to create it. Very few double bands, or reactive sites, exist in the rubber molecule. This arrangement of the structure renders butyl rubber very stable and quite inert to the effects of weathering, age and heat. The fact that it is a hydrocarbon material indicates very low water absorption by the polymer. The many side-groups attached to the chain produce a high degree of damping, but since they are not large in size and are regularly spaced, they do not interfere with the orientation of the rubber molecule. Thus, butyl gum exhibits dynamic softness, low modulus and high tensile strength.

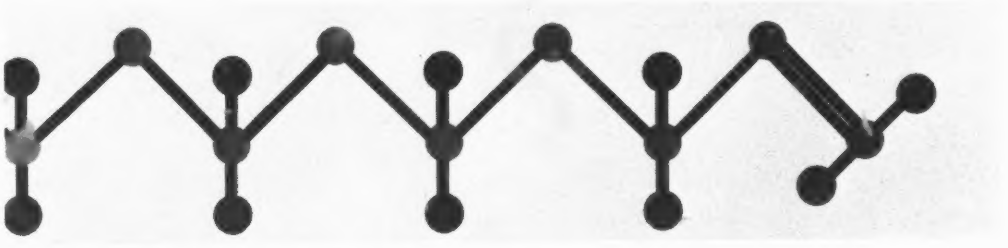

Figure 1 -- Molecular structure of butyl rubber.

The polyisobutylenes differ from butyl rubber in that they are produced over a wider range of molecular weights, and are essentially free of double bonds in the polymer chain.

This dense, long polymer chain results in an extremely inert, durable and impervious binder for sealants and mastics. It is possible to produce a system that will be nonstaining, resistant to the effects of weather, oxidation, heat and ultra-violet energy, and have good low-temperature flexibility, low water absorption, good vibration damping, and resistance to low-temperature compression set. Adhesion to glass, aluminum, steel and masonry components is excellent and tensile strength, for an uncured system, is good.

COMPOUNDING CONSIDERATIONS

We might, for the sealant manufacturer's benefit, discuss briefly some of the compounding considerations important to the preparation of these systems, and indicate some facts that might be the basis for choosing between butyl rubber and polyisobutylene, for a particular product.

The low molecular weight polyisobutylenes are tacky and viscous, and can be used to advantage in gun-grade compounds.

The higher molecular weight members of the family are solid rubbers with all the behavior characteristics of butyl rubber. They are somewhat more stable than butyl, and we have had better success in protecting them against ultra-violet degradation. Butyl rubber and polyisobutylene have equally high levels of filler acceptance. Each responds well to softening and plasticizing with polybutene oils. High solids sealants are possible with each polymer and neither, if properly compounded, presents shrinkage problems.

Butyl rubber has the advantage of being somewhat lower in cost, and it is easier to get into solution.

The elastic recovery of both butyl rubber and the higher molecular polyisobutylenes is good, particularly when one considers that these materials are uncured.

Figure 2 will serve to illustrate quantitatively the polymer's ability to recover from conditions of compression and extension.

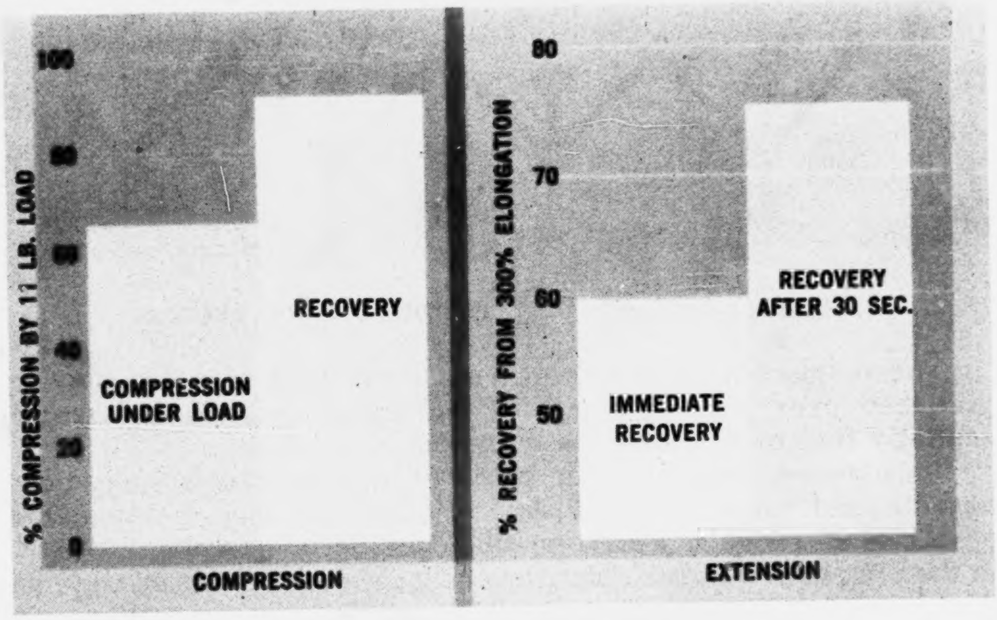

Figure 2 -- Elastic recovery of polyisobutylene.

Test specimens of medium molecular weight polyisobutylene were compressed for three minutes under a force of 11 pounds. The force was removed, and the specimen was allowed to recover for 60 minutes in a prescribed temperature cycle. The imposed load caused a 35% compression of the specimen. The compression set measured at the end of 60 minutes was 7%.

Molded dumbbells were stretched to 300% elongation at 80° F, held at this elongation for one minute, and then released. Immediate recovery from 300% elongation amounted to 60% and 30 seconds after release, amounted to 75%.

3

Butyl rubber and polyisobutylene have the ability to bind large amounts of filler, and to hold them without cracking. Since they are hydrocarbon materials, they have a relatively low ability to wet pigments. It is recommended, therefore, that compatible polar materials such as rosin esters be included in the compound to improve pigment wetting and dispersion. Flow and sag can be controlled by the use of fibrous fillers and thickeners.

Physical consistency of the sealant can be adjusted through the selection of the grade of polyisobutylene. Dilution can be accomplished by the incorporation of mineral spirits or polybutene oils, and tackifiers can be added if required.

Manufacturers have a great compounding latitude in the formulation of butyl sealants. A wide variety of durable, high quality materials can be produced within the parameters of performance, economical cost, and manufacturing capability.

These afford the contractor one-part systems with virtually unlimited storage life. Application is accomplished with ease, and clean-up is simple.

PERFORMANCE CHARACTERISTICS

The architect and builder can specify and use with confidence butyl rubber and polyisobutylene sealants for joint seals involving aluminum, steel, glass, plastics, masonry and other ceramics. Bulk sealants, ribbons, tapes, and composite systems are available commercially from recognized and reliable suppliers. These systems remain flexible indefinitely. Temperature variations from -40° F to 230° F have no adverse effect on the sealant. They are impervious to moisture, and have extremely low water absorption levels. The stable, inert nature of butyl imparts to the joints unusual resistance to the effects of weather, sunlight, heat, and oxidation.

We have had butyl rubber membrane on test as irrigation ditch liner in northern Utah for over 12 years. While this region gets extremely cold in the winter, it is arid in the summer, and the number of days of sunlight per year is high. Service is severe. The membrane is subjected not only to weather conditions, but to abrasion from rocks, soil and blowing sands. It is exposed to puncture and tearing by animal hoofs and birds. Samples are periodically removed, and measurements made of tensile strength, modulus, elongation, and burst strength. In the years the material has been on test, we have noted insignificant changes in the physical properties. This was a vulcanized butyl system, and the results cannot be validly translated to the behavior of uncured systems such as butyl sealants. The results are indicative, however, of the superior weather resistance of these polymers in any properly compounded form.

The elasticity and dynamic behavior of butyl rubber insure adequate vibration damping and the absorption of stresses caused by unequal rates of expansion or contraction of structural members.

Butyl rubber is nonstaining and noncorrosive. Decorative metal members will be unaffected by contact with butyl sealants. Colored compounds are possible and, since the polymer does not discolor with age, color stability and tint fidelity of the sealant is good.

These sealants possess tensile strength in the neighborhood of 115 to 250 lb. per square inch with elongation varying between 50% and 250%. Products ranging from 25 to 50 points in hardness value are obtainable. Shrinkage is less than 5%.

Butyl sealants are adaptable to most of the typical masonry and metal joint systems. A few are shown in Figures 3-6. They are schematic, general representations, and are not intended to be specific designs.

Tapes are used in Figure 3 as the flexible bedding component in combination with a curable, two-part sealant.

In Figure 4, the butyl tape in conjunction with the butyl sealing compound comprise the joint in sealing glass or panels.

Excellent adhesion producing a completely watertight and weathertight joint is obtained with the composite gasket shown in Figure 5. The cured butyl rubber core provides resilience and dimensional stability. The surrounding layer of uncured butyl beds the glass or panel, and seats this portion of the system in the frame. Pressure is exerted by the mechanical stop, which, itself, is bedded in a butyl rubber tape.

In Figure 6, one notes the manner in which butyl tapes and preformed ribbon sealants are used to provide the seal for a metal mullion and expansion joint.

RECENT PROGRESS

Since this review of butyl rubber in sealants is part of a research correlation conference, in keeping with this theme we would like to relate briefly some progress we have made in developing new materials that may have physical properties and performance characteristics that will make them interesting as sealants. We are encouraged by our preliminary results and hope this preview will be of interest.

Manufacturing facilities are now available for producing butyl rubber in latex form. This makes the polymer available for the first time in a new, readily usable, physical form. Butyl latex is a high solids, mechanically and chemically stable emulsion of butyl rubber. It contributes to a system all the physical properties and performance advantages common to butyl rubber. To the compounder who is interested in water-based calks and sealants, it offers ease of mixing and formulation. We have yet to resolve certain questions of shrinkage and drying rate, but performance of the sealants compounded from it has been the same as one would expect to get from a regular butyl rubber system.

So far in our discussion of sealants, we have made no reference to two-part, cured butyl compounds. The low unsaturation in the butyl rubber molecule accounts for its stability, and its inertness to the destructive effects of weather and age. It also, unfortunately,

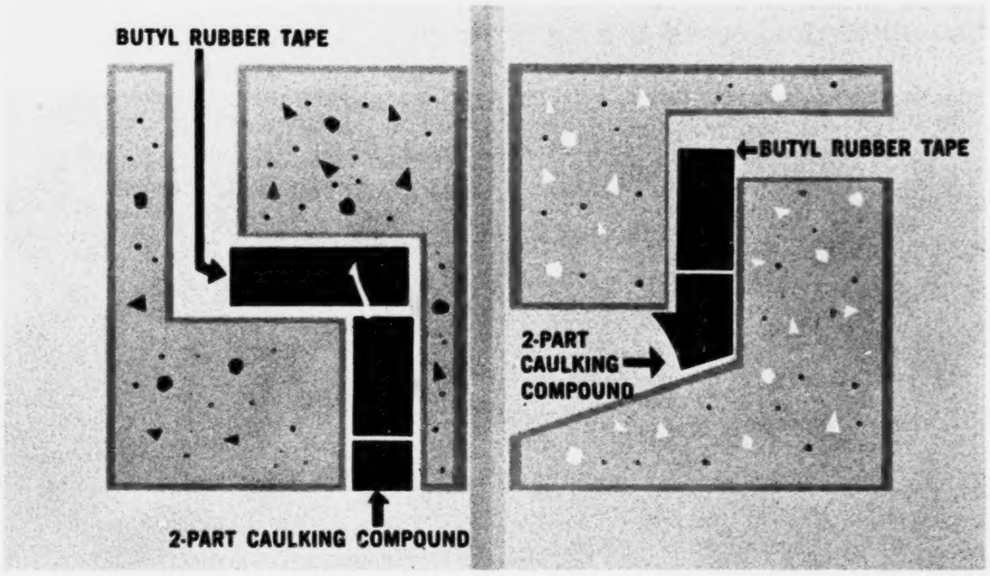
BUTYL RUBBER TAPE
2-PART CAULKING COMPOUND
BUTYL RUBBER TAPE
2-PART
CAULKING
COMPOUND

Figure 3 -- Concrete joints. Left: Vertical lap joint; right: Horizontal lap joint.

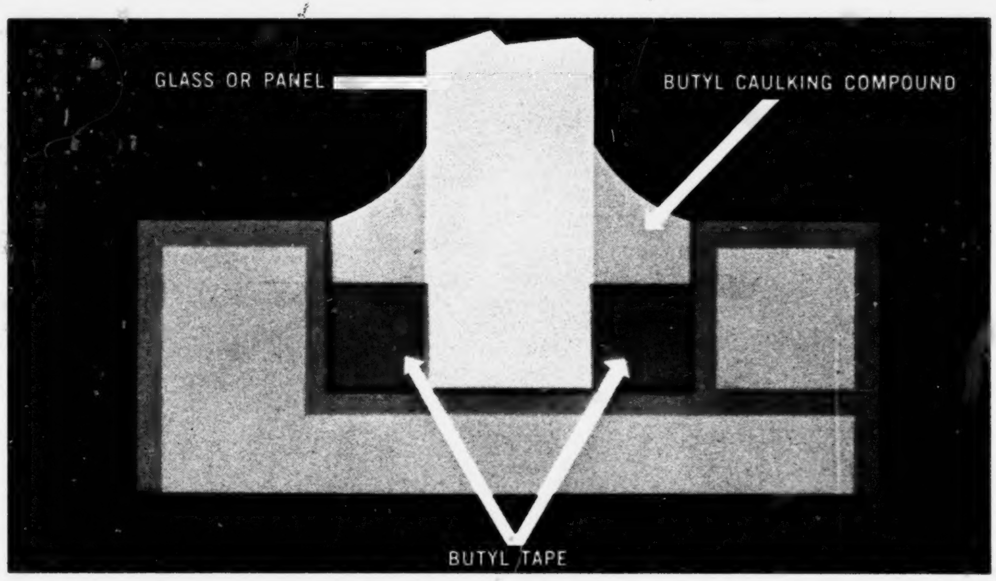
GLASS OR PANEL
BUTYL CAULKING COMPOUND
BUTYL TAPE

Figure 4 -- Typical joint seal using butyl tape and sealing compound.

accounts for the slow rate at which butyl rubber cures. Because a satisfactory rate of cure and state of cure are dependent on elevated temperatures, we have not had much success with self-curing systems.

Through research and product application work, we have recently developed a modified butyl rubber. This modification involves introducing some chlorine into the polymer chain to provide sites for cross-linking or curing, in addition to the double

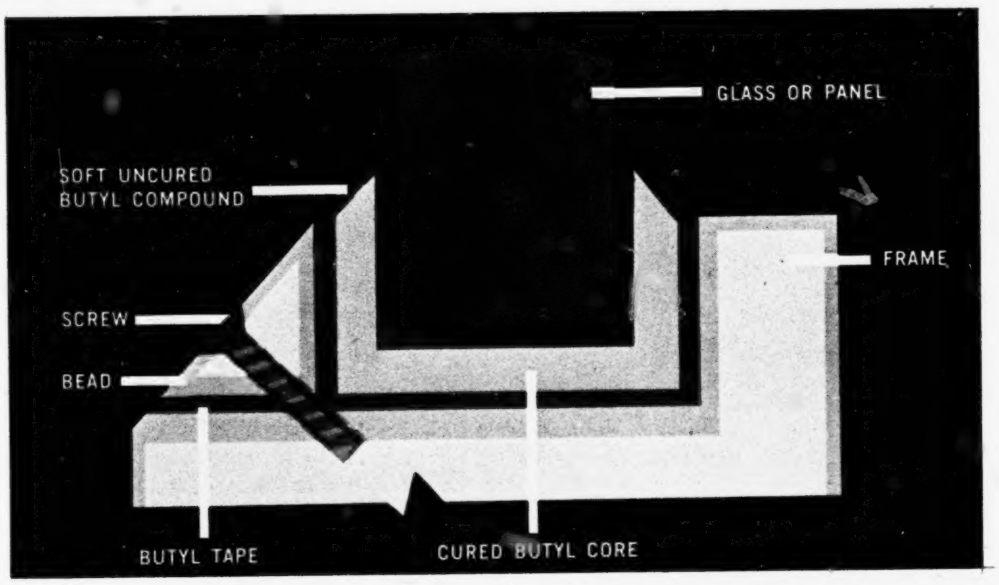
GLASS OR PANEL
SOFT UNCURED BUTYL COMPOUND
FRAME
SCREW
BEAD
BUTYL TAPE
CURED BUTYL CORE

Figure 5 -- Composite gasket.

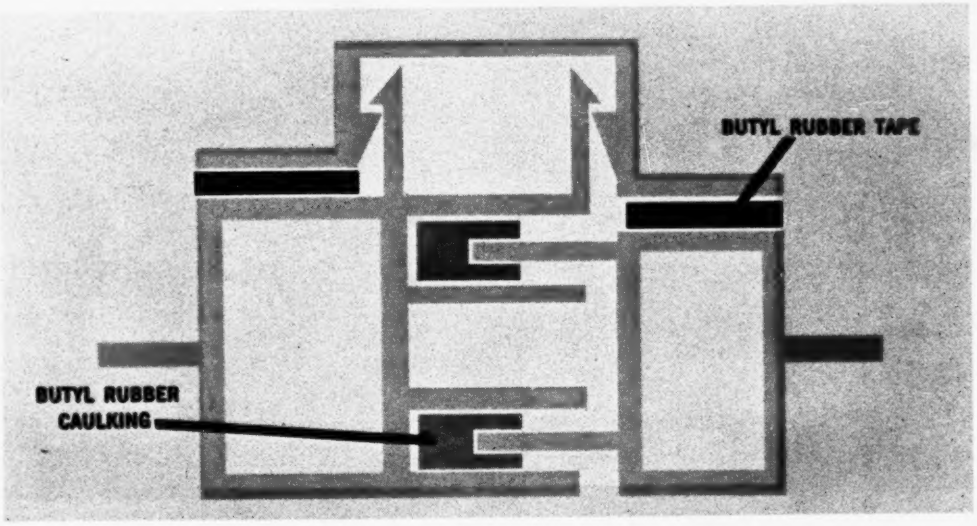
BUTYL RUBBER TAPE
BUTYL RUBBER CAULKING

Figure 6 -- Vertical metal mullion and expansion joint.

bonds that now exist. Using a laboratory technique for reducing the molecular weight, we have produced a self-curing vehicle for knife-grade calks.

Pilot formulations have been prepared, and some very preliminary tests performed. Tensile strength and elongation values of 300 lb. per sq. in. and 800%, respectively, have been obtained. In rubber technology, tensile strength and modulus are used as an index of cure. Because of the difficulty of preparing tensile specimens, and in an effort to eliminate test factors that might have clouded the results, we tested the system in compression.

In Figure 7 we have plotted the percentage of deflection against load in pounds per square inch for a series of specimens cured at room temperature for 24 hours, three weeks, and six weeks. It can be noted that, as time of cure increases, the load necessary to produce a given deflection increases. This indicates that we are, in fact, getting a substantial cure at room temperature. Much work remains to be done, including the development of a feasible process for producing the vehicle in a consistency suitable for gun-grade systems. We are encouraged by the results, and are continuing our efforts so that these improvements in the field of butyl sealants can be offered to the building industry.

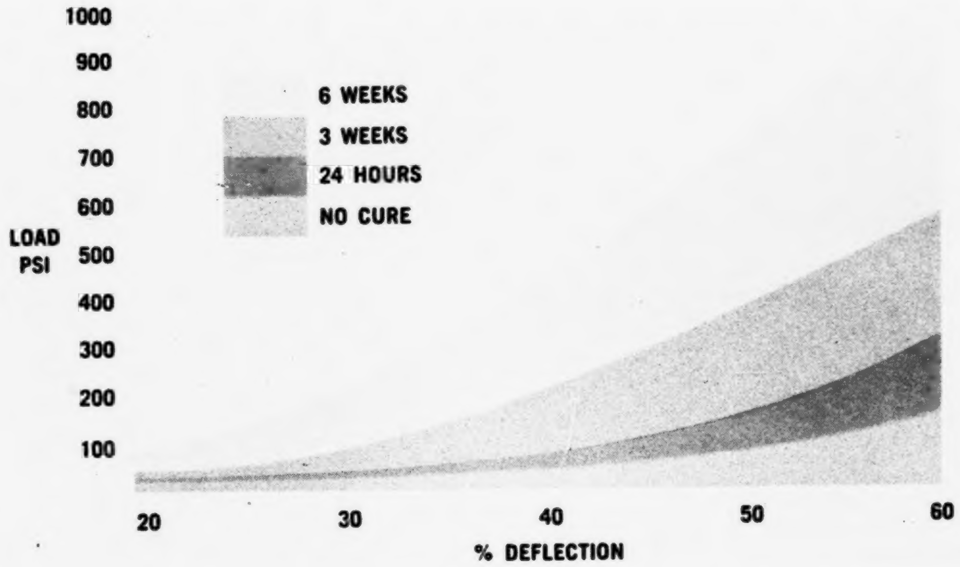

Figure 7 -- Two-part chlorobutyl sealing compound.

Finally, much interest has been generated recently in ethylene-propylene rubber. Advances in catalytic and polymer chemistry have produced this new elastomer, which is unexcelled in resistance to weather, oxidation, ozone, and age. It is a resilient rubber and exhibits low-temperature behavior as good as that of natural rubber. With such properties, and a polymer cost in the range of styrene-butadiene or butyl rubber, it is an obvious candidate for gasketing and sealing applications.

Much work remains to be done, and the activity in many areas of application is lively. As we develop definitive technical information of value to the building industry, you will be the first to know.

We benefit greatly from these exchanges of information and views. Through forums such as these, we constantly reorient our efforts to the needs of the industry. We are able to develop a more sophisticated approach to the problems of the architect and the builder and, we hope, improve our capability to contribute. In my opinion, there is no activity in which we participate that exhibits a higher level of technical excellence than these conferences. In company with the other organizations participating, we are as always, at the invitation of the Building Research Institute, pleased to contribute to the progress of the industry.

Epoxy Joint Sealants

By C. V. Wittenwyler, Shell Chemical Company

Abstract: Epoxy sealant compositions are still experimental. They have good adhesion, water resistance, durability under extremes of weather, light color, and good cure and can be easily applied. The epoxy resin most widely used in sealants is the bisphenol epichlorohydrin type, which ranges from liquids to solids. Epoxy sealants must be modified, which may be done by adding plasticizers, curing with a flexible curing agent, incorporating a flexible monomer or polymer, or chemically modifying the resin. They may be used for applications where intermediate distensibility is needed. Significant progress has been made in recent years, and further improvements may be expected.

ALTHOUGH THIS IS THE FIFTH research correlation conference of the Adhesives and Sealants Planning Committee of the Building Research Institute, this is the first time epoxy resins have been included in discussion of sealants. This is due in part to the comparative newness of the epoxy resins, which were introduced commercially in 1950, and in part to the normally rigid nature of epoxy resins. However, recent developments with epoxy resins have shown that modifications can be made to provide more elastic properties than those normally associated with these resins. Modified epoxy resins of this type have elongation properties in a range that now makes them of potential interest as sealants.

The field of sealants for the construction industry is a broad and somewhat nebulous one. The function of a sealant is to seal a crack or joint for a given period of time, to prevent water, dust and air from entering. Currently-used sealants range from hard glazing compounds like vegetable-oil putty, with an elongation of about 5% after setting, to the soft, elastomeric sealing compounds with elongations of over 300%. The current epoxy resin compositions have elongations in between these two extremes. Hence, they cannot be used in the most demanding applications, but can be used in cases where high elongation is not the major consideration. The new epoxy compositions have high adhesive strength, toughness, weather resistance and chemical resistance.

WITTENWYLER, C. V. Group Leader, Construction Applications, Shell Chemical Company; member, American Chemical Society, ASTM, BRI, Highway Research Board.

DEVELOPMENTAL PROGRESS

In the 12 years since epoxy resins were introduced, many branches have sprung from the original tree. The first epoxy resin was a bisphenol epichlorohydrin type, made from petroleum products. Although this is still the most widely used epoxy resin, many other types have been developed. One of the early epoxy compounds was the epoxidized oil made from vegetable oil and hydrogen peroxide. This material is widely used in conjunction with polyvinyl chloride resins, but is not a resin or a plastic in its own right. Epoxies have also been made by modifying the original plastic, phenol formaldehyde resin. The glycidated phenolic resins that result are always dark in color, but have high strength at elevated temperature, and good chemical resistance.

Other types of epoxies which have been introduced more recently are the peroxide or cyclo-aliphatic types. These are made by epoxidizing various unsaturated cyclic materials, such as vinyl cyclohexene, with hydrogen peroxide. They have the advantages of low viscosity and good performance at high temperatures.

The most recent additions are the epoxidized polyolefin types, introduced about two years ago. Although in synthesis they are related to the cyclo-aliphatic type, they have different reactivities, and their polymers have distinct properties. Each of these epoxies, the bisphenol, the epoxidized oils, the cyclo-aliphatics, the glycidated novolacs, and the epoxidized olefins have unique properties which define their end-uses.

PROPERTIES DETERMINE END-USE

The wide variety of products which are now grouped together under the name "epoxy" makes it quite difficult for those who are not polymer chemists to understand exactly what is meant by the term. Each member of the family is handled and used differently, to obtain the best results. Their polymers have separate properties which make each suitable for specific applications. In the present discussion on epoxy sealants, we will limit ourselves to the epichlorohydrin-bisphenol type. Even within this family, there is still a broad array of individual members. They range from liquids with the color and viscosity of honey to hard, tough, amber-colored solids. For sealant applications, the liquid types which require no volatile solvent are used, because of handling convenience.

Normally, liquid bisphenol epoxy resins are cured with polyamines. Usually, the ratio of resin to amine is about 10/1 by weight. When the amine is combined with the resin, they react at room temperature, giving off heat. The polymer from this reaction is a hard, tough plastic with high strength, but insufficient distensibility for sealant applications. At room temperature, the tensile strength of such a cured polymer will be about 10,000 psi, and it elongates only 2% before rupture occurs. These properties are clearly in the plastic, rather than the elastic, range. The plastic, though hard, has many of the properties desired of a good sealant. It cures quickly at room temperature (about 3-6 hours); has excellent adhesion to wood, metal, glass, masonry, and ceramic materials; has good resistance to water, sunlight, and weather; has a mild odor; is light colored; and may be pigmented to any color desired.

By way of illustration of these properties, a major use of epoxy resins is in formulating high-strength adhesives. The Air Force B-58 Hustler, a supersonic attack bomber, is assembled with over a thousand pounds of epoxy resin. Aircraft adhesives require not only high strength but a high degree of reliability. The adhesive qualities of the epoxy resins are outstanding.

Epoxies are preferred resins for making rocket and missile tubes, because of their high strength and adhesion. Rocket tubes are made by winding glass fibers saturated with epoxy resin around a mandrel, and curing the resin. Pound for pound, such structures have greater tensile strength than steel. The acceptance of epoxies, rather than other classes of resins, in this application is due largely to their ability to bond so strongly to the glass fiber. Glass-resin pipes, made in the same way as the rocket tubes, are used in severe industrial service because of their excellent corrosion resistance to many chemical solutions, and their light weight.

With these attractive properties it seems quite useful to explore the epoxies' value as sealants. The development of epoxy sealants is quite recent and still in the experimental stage. The first step in this direction is to devise a means of modifying the resin properties away from the plastic type and toward a softer, more elastomeric type of polymer. There are several ways of doing this, physically or chemically:

1. Modifying with plasticizers
2. Curing with a flexible curing agent
3. Incorporating a-flexible monomer or polymer
4. Chemically modifying the resin.

All of these mtehods have been used to obtain more elastic epoxy polymers with some degree of success.

PLASTICIZERS

Plasticizer modification has been used successfully to make a unique type of surface sealant. We are all aware of the damage wet freezes do to roadway surfaces during the winter months. The degradation of concrete is caused by water getting into small cracks and pores, and freezing with an expansive force great enough to enlarge the voids. Successive freezes cause successive enlargement, and ultimately, some form of maintenance or correction must be carried out.

A heavily traveled bridge in New York City has been treated with epoxy sealants in a unique form of preventive maintenance. The wearing surface of the portland cement concrete bridge deck was sealed with a liquid epoxy resin, which was modified with a plasticizer to obtain greater elasticity. The compound was sprayed on the road surface about 1/16 in. thick and, to prevent a slippery surface condition from developing, the wet resin was sprinkled with fine grit. As the resin hardened, a highly skid-resistant surface was formed. After a year of service, which included a severe winter, the number of chuckholes on the bridge deck was reduced from a normal average of about 100 to only 2. An added bonus in this application was the leveling action and the skid-resistant texture of the final surface.

The use of the plasticizer here was essential, since the thermal coefficient of expansion for epoxy resins is about 50% greater than that of portland cement concrete. Unmodified epoxy resins in such applications would cause stresses as the temperature cycles from 0° to 150° F. These stresses can be great enought to rupture the portland cement. The plasticizer modification has proven entirely satisfactory for surface-sealing of this type. Even small cracks can be filled without reflection cracks, as shown in Figure 1. Tensile tests to measure the adhesion of this system to the concrete generally result in failure of the concrete itself, rather than breaking of the resin or the resin bond. This epoxy system has a tensile strength of about 500 psi, and an elongation at break of about 40%.

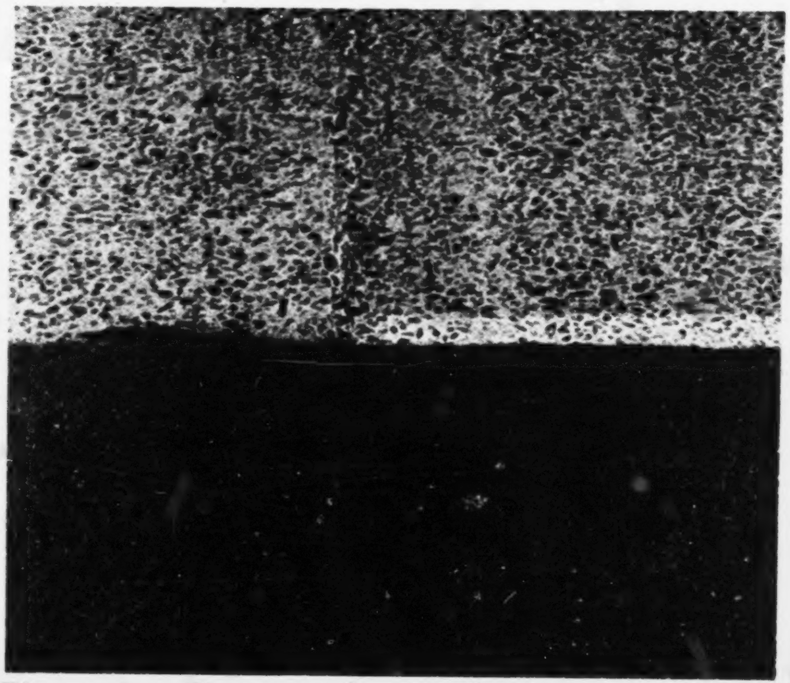

Figure 1 -- Epoxy surface sealant over bridge deck cracks shows no failure.

Tensile strength and elongation value were determined on specimens defined in ASTM Method D-412 for vulcanized rubbers. The test specimen in 1/8 in. thick x 1/4 in. wide, and the test span is 1-1/2 in. long. Normally, crack and joint fillers are not subjected to stresses along the long axis in this manner, but rather along the short axis. Consequently, lower elongations at break will result with the shape factor used in crack sealants. Accordingly, while this plasticized epoxy resin system is adequate for surface sealing and nonworking cracks, it is not satisfactory for joints where any degree of movement is expected.

FLEXIBLE CURING AGENTS

There are several room-temperature curing agents which will provide greater flexibility in epoxy resin polymers. One of the most common types is the polyamide resin. Polyamide resins, like epoxy resins, are available in liquid from, and to use them, approximately equal quantities of epoxy resin and polyamide resin are stirred together. The polyamide resins used for this purpose are quite viscous, about like cold molasses. Consequently, they are more difficult to apply than the polyamine catalyzed systems. Such a mixture sets up quickly in four to eight hours at normal room temperatures, resulting in a tough polymer. Its tensile strength is approximately 8,000 psi, and it has an elongation of about 12% at break. This system is used as a masonry sealant for inactive cracks and holes where high elongation is not needed. The system has high adhesion, is easy to use, adheres to alkaline materials, and is not affected by exposure to weather and water. It cannot be used as a sealing compound for working joints because of its limited elongation.

FLEXIBILIZERS

There are several flexible polymers that can be used either as a physical mixture or as a coreactant with epoxies to form a resinous mixture with high elongation. Some types of synthetic rubber, i.e., nitrile rubbers, can be used with special epoxy resins and conventional polyamine curing agents to get elongations of about 100% and tensile strengths of 2,000 psi. Since the rubber does not react chemically, this composition loses much of the original strength and chemical resistance of the epoxy resin itself, as is the case when plasticizers are used.

Liquid polysulfide rubber polymers, by way of contrast, have reactive sulfhydryl groups which react chemically with the epoxy resins during cure. Such epoxy-polysulfide compositions should not be confused with the pure polysulfide polymers. The epoxy-polysulfide type of resin system gives a higher strength and better chemical resistance than nonreactive elastomeric modifiers. One growing use for the epoxy-polysulfide system is for sealing new portland cement concrete against old concrete. Normally, when placing new concrete in thin layers over old, poor bonding results and frequent failures occur. When a mixture of epoxy and polysulfide rubber is spread over the surface of the old cement, and new concrete applied before the resin has cured, a strong, lasting bond can be achieved. This composition, now covered by a Federal Specification, is widely used in construction for patching and resurfacing masonry structures. The success is due in part to the adhesion and flexibility of the system, and partly to its ability to cure in contact with the wet, alkaline concrete surface.

MODIFIED RESINS

Although these systems perform well in their respective fields or applications, they are basically modifications of a plastic material in order to produce elastomeric properties. Theoretically, better performance would result from designing a resin molecule which, when cured, would be an elastomeric polymer. Such molecules may be designed using classical chemical principles, such as long-chain, linear molecules, minimum cross-linking, restricted intermolecular attraction, and a coiled-chain structure. Making such a molecule in the laboratory is much more difficult than designing it on paper, but progress has been made in this direction. Several such new epoxy resins have been produced, and they show promise for sealant applications when high elongation is added to the properties normally associated with the epoxies. While they are quite recent, experimental sealing compounds have been made that perform well in the laboratory. While high elongations are not difficult to achieve by chemical modification of epoxy resins, it is difficult to maintain high elongation over a wide temperature range.

Many members of the plastics family exhibit characteristic changes in state as the temperature is changed. This transition is illustrated in Figure 2, which shows the elastic modulus variation with temperature change. At low temperatures, the system has a high modulus in the range of crystalline or glassy materials. As the temperature is raised, the polymer becomes softer, and is best characterized as leathery, with slightly higher elongation. Beyond this transition stage, a rubbery region is encountered. Here the modulus and other properties closely match those of natural rubber. Natural rubber exhibits this modulus over the temperature range of about -40° to 400° F. For plastics, this rubbery state exists over a much narrower temperature range. As the temperature is raised still higher, the system still shows elasticity, but also exhibits a marked degree of flow. Finally, at even higher temperatures, the polymer loses its elastic recovery, and shows an apparent state of liquid flow.

For sealant applications, we want a system with rubbery characteristics, and this state should extend at least over the range of 0° F to 150° F. When a blend of a 25%w long-chain epoxy resin and a

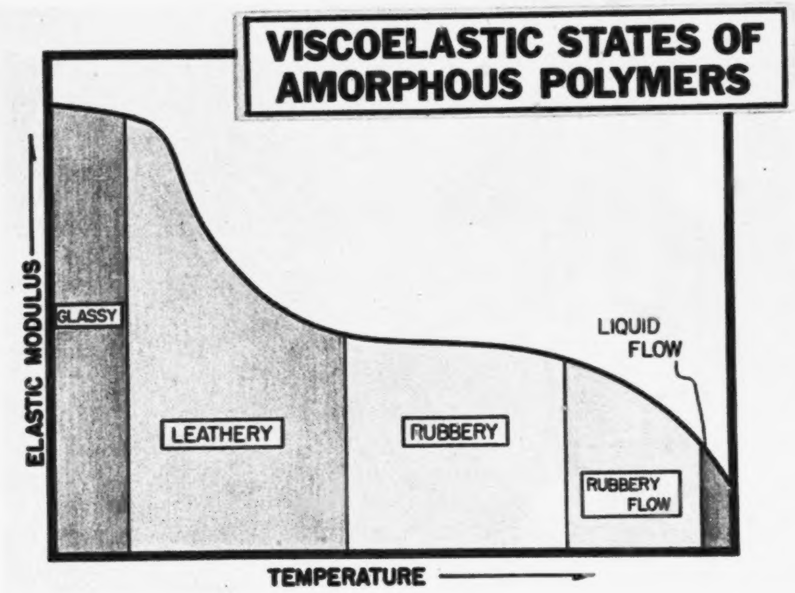

Figure 2 -- Effect of temperature on typical thermoplastic resin. Source: A. V. Tobolsky, J. R. McLoughlin, J. Polymer Science, 8, 543 (1952)

bisphenol epoxy resin is cured, an elongation of 160% is obtained at 77° F. However, the elongation of this material drops to only 9% at 0° F, and 47% at 150° F, as shown in Figure 3. By increasing the amount of long-chain resin to 50%w, there is a slight sacrifice in elongation at 77° F and 150° F, but a significant gain at 0° F. By using 75% of this resin, a smoother curve is obtained, with an elongation much more independent of temperature variation. The corresponding tensile strengths for these systems are shown in Figure 4.

This resin composition is blended with thickeners and pigments to make a sealant. Prior to use, a small amount of curing agent is mixed with the resin, and the blend applied with a calking gun, as shown in Figure 5, or it may be applied with a knife. Alternatively, the thickener may be eliminated in order to provide a low viscosity, pourable, self-leveling type of sealant as shown in Figure 6. It handles similarly to conventional calking compounds, and has little tendency to string. It must be used within four hours after mixing, since the reaction of the resin and the catalyst tends to increase the viscosity of the system, and makes application more difficult after that time.

Once it is applied, it wets out nearly any clean surface, and forms a strong and enduring bond. It contains no volatile solvents, and does not skin over. It hardens without evaporation or air oxidation, by homogeneous chemical reaction. It is an excellent nonconductor of electric current. Laboratory tests show it has good resistance to age embrittling, but this must be confirmed by actual outdoor test installations.

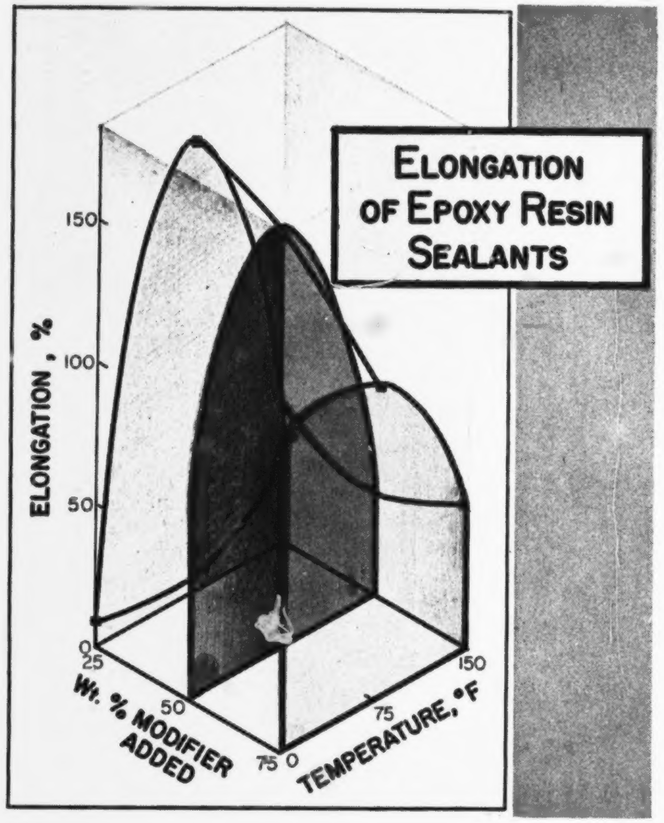

Figure 3 -- Elongation variation of epoxy sealants with temperature and composition changes.

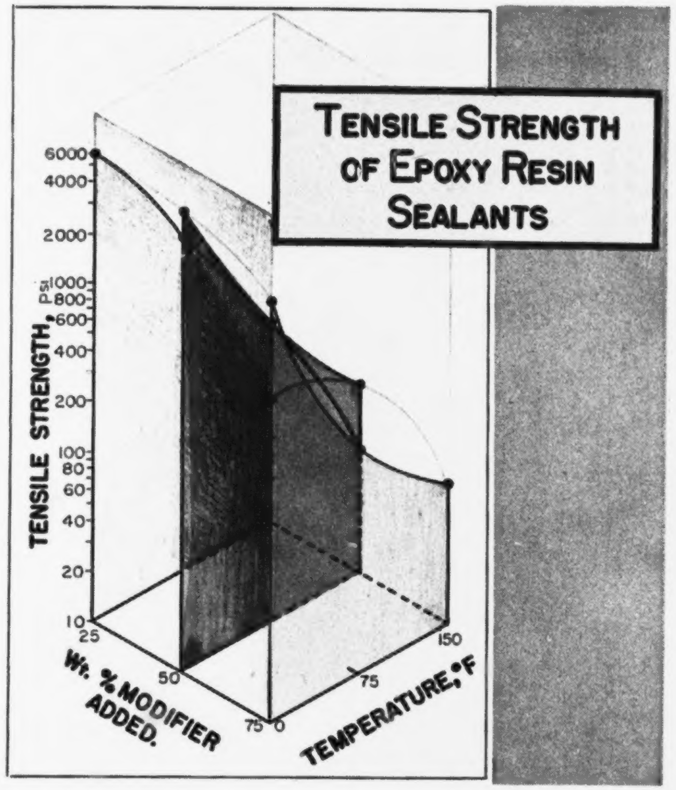

Figure 4 -- Tensile strength variation of epoxy sealants with temperature and composition changes.

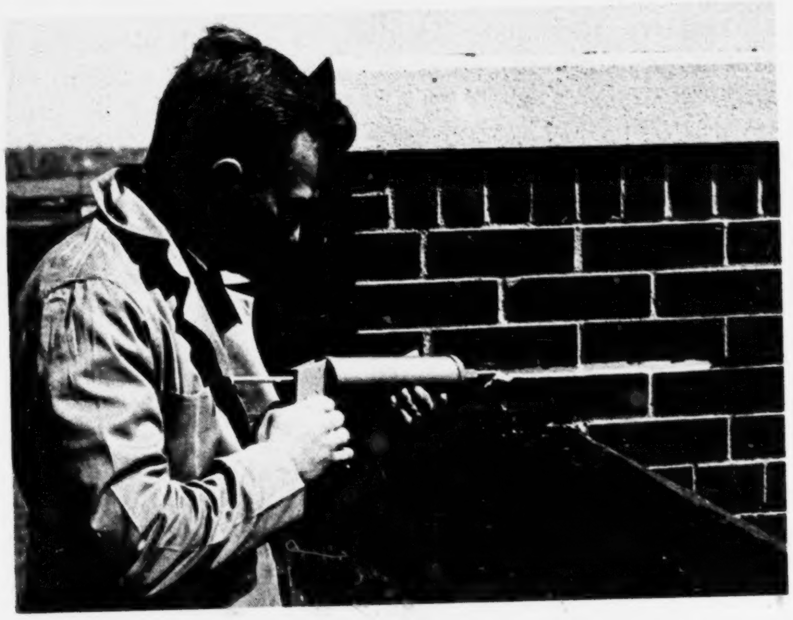

Figure 5 -- Application of non-sagging epoxy sealant.

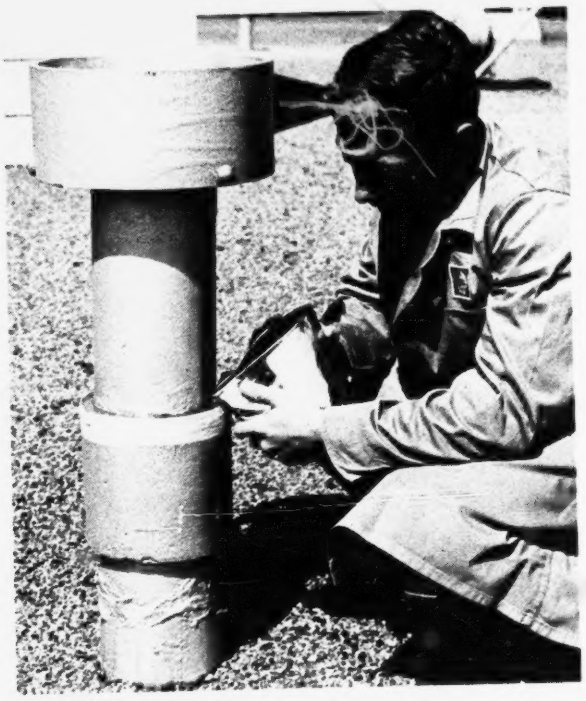

Figure 6 -- Application of self-leveling epoxy sealant to pipe joint.

Results to date are encouraging; however, epoxies are not cure-alls. They require thorough blending of resin and curing agent in the proper proportions. They can be used only over clean surfaces, and at temperatures of 50° F or above. They cannot be used where high distensibility is required over a wide range of temperatures. Here, as in other fields, they can make sizeable contributions when used within their proper limits. The cooperation of the architect, the manufacturer, the contractor, and the development chemist is needed to provide opportunities for this promising new sealant material to help solve some of the sealing problems in the building industry.

CONCLUSIONS

We have seen that epoxy resins are capable of wide variation in physical properties, which approach those needed for an ideal building sealant. There is not one, but a family of epoxy sealant compositions for various types of service costing approximately $9.00 to $21.00 per gallon. Most of these compounds are new, and relatively unproven outside of the laboratory. They have good adhesion, water resistance, durability under extremes of weather, light color, good cure, and can be easily applied by pouring, knife, gun, or trowel. On the other hand, they require blending of two components, and have a limited usable life under mixing. They have limited distensibility over the wide temperature range desired. Significant progress has been made in recent years, and further improvement may be expected. At the present time they may be used for application where intermediate distensibility is needed. As more data are gathered under different conditions of exposure, modifications can be incorporated to eliminate areas of weakness, and improve areas of strength.

Open Forum Discussion

Moderator: Alex O'Hare, Miracle Adhesives Corporation

Panel Members: Messrs. Fitzgerald, Fosgate, Hilbush, LeFave, Maneri, and Wittenwyler.

Mr. O'Hare: There's been a lot of stress laid upon the fact that, with any and all of the sealants discussed, the most important part of the installation is the proper cleaning of the joints, and yet this particular topic has not been elaborated on in any of the papers. Does any member of the panel know of any mechanical means for properly cleaning joints prior to installing sealants?

Mr. Maneri: There are a variety of means of cleaning joints and joint areas, depending upon the specific situation involved. For instance, if you want a clean masonry joint, we definitely recommend wire brushing or blowing, or some other way of getting rid of all the dust. Often we recommend cutting back the joint with a diamond saw to get good virgin substrate. This is the ideal way to clean the joint. With metals, generally, wiping with a good solvent, such as xylol, methylethylketone, or a combination of xylol and acetone is a very good way to clean the joint. I think the same thing is true with glass. The thing you want to avoid is the use of a cleaning material which may act as an intermediary layer or film between the sealant and the substrate to which you want it to adhere. For instance, on glass, if you use a detergent, it will act as a release agent for a number of sealants.

Mr. O'Hare: By a surface conditioner, do you mean a primer?

Mr. Maneri: At least not in the sense it is normally used in the building industry. Primer, according to Webster, is the first thing you put on a surface, and from this standpoint it is a primer, since it goes on before the sealant. But to most people in the construction field, a primer would mean a film-former, or transition layer, between the sealant and the substrate. The surface conditioner we're talking about is not this sort of thing. It is a chemical layer, virtually a monomolecular layer, of material formed on the surface which has a chemical attraction to both the substrate and the sealant, and this does give you added advantages. The silicone sealants, I might add, have good adhesion to glass and metal without the use of a surface conditioner, but using one is like buying insurance.

Mr. O'Hare: I was smelling this particular sealant sample you have here, and it smells like acetic acid. Do you have any corrosion problems with this, or does your surface conditioner take care of it?

Mr. Maneri: I am glad you asked that as I didn't get a chance to go into it in my paper. Actually, there are two types of silicone joint sealants being marketed. One of these types does give off a smell of acetic acid, or vinegar. This is part of the chemical reaction which is taking place. We have had quite a bit of experience industrially with this type material and there is no question, especially in the electronics field where it is used near copper wires and where the electrical properties are very critical that you have to be aware of the problem so that you handle the material properly. It has been evaluated by a number of independent sources in the construction field, and we've had no trouble at all with corrosion. The second type, on the other hand, does not have an acetic acid by-product.

Mr. LeFave: Very often, an ounce of prevention is worth a pound of cure. Proper selection of the filler behind the sealant is very important. In the assembly of the components, if care is taken to keep the joints clean, and if you give yourself enough room to work in the joints, you avoid the need for coming back and cleaning up a messy job, before the sealant is applied.

Mr. O'Hare: This should be a fruitful field for future development. Probably we should recommend a conference on cleaning of joints for our next year's BRI program. Is there anyone else who has had experience with cleaning of joints who would like to say something?

G.M. Lewis, Cafritz Company: In cleaning joints for swimming pools, we find it advisable to use the very coarsest sandpaper possible on a disc, and follow it up with etching. This is the only method I have found that is working very well.

Unidentified panel member: We agree with that, and also agree that the use of primers is quite advisable. Mechanically, you can compare sandblasting to the disc method. I think it serves an equally good purpose, and is a lot easier than the other. We feel that a primer tends to compensate for rather imperfect cleaning jobs.

H.M. Johnson, Union Carbide Corporation: In the ASA specification tests under ultra-violet and moisture exposure, are there any figures on time of exposure of the various sealants required to reach minimum values for adhesion and elongation? It might be compared to a degradation rate.

Mr. Fosgate: In terms of polyurethane sealants, with which we are familiar, we have not run tests to degradation to reach the minimum values. The ASA standards don't require this, but I think it would be an excellent suggestion for future study to run this test to degradation.

Mr. LeFave: We've run these U-V tests for as long as a month, with frequent changing of bulbs, and we find that there is so much variation between sealants, including sealants out of a given batch, that we have some qualms about the test. Certainly, it seems to be a practical one, but the correlation we've been able to establish is not good at all.

Unsigned question: Would you care to state the polymer content, or the minimum polymer content range, for your one-package polysulfide?

Mr. LeFave: Unfortunately, it's quite high. Offhand, I'd say it's somewhere around 65 to 70%. It has a specific gravity of 1.5, which would calculate to around 65%. We felt that, first of all, we had to have exceptional performance to compensate for the price of the product. We feel like the silicone people do about their product that this performance is a necessity.

Unsigned question: What is the price range of the various materials?

Mr. Maneri: There is a range somewhere between $35 and $45 per gallon, depending upon the package, and the quantity involved in the job.

Mr. O'Hare: That covers the silicones. What is the range on the butyls?

Mr. FitzGerald: I would have to refer to some of the manufacturers on price. It's my belief that for this type of sealant, dependent of course upon polymer content, the price is probably in the range of $7 to $12 per gallon. If that's wrong, I certainly would be willing to accept a correction from the floor.

Mr. O'Hare: It's quite obvious that the price range will be determined more or less by the polymer content of the sealant.

Mr. Hilbush: The chlorosulfonated polyethylene runs between $11 and $15 per gallon.

Mr. Wittenwyler: This is a little bit difficult to answer for the epoxy sealants, because these are not commercially available. Now we have a figure based on the raw material cost, plus manufacturing, profit, etc., which can be extrapolated to a range of about $9 to to $21 per gallon.

Mr. LeFave: The one-part polysulfides range from $30 to $35 per gallon. This will come down in three or four months to a range of $20 to $24 which, by our calculations of labor costs, will make it quite competitive with added advantages.

Mr. Fosgate: In speaking of price per gallon for the polyurethane sealants, we have to refer back to the two-component systems, which are usually sold in units. A unit of one gallon is usually only three-quarters full to allow head space for mixing. In the case of the polyurethanes, the unit is eight-tenths of a gallon in the gallon unit, and the same proportion in the five gallon unit. This material sells for approximately $12 to $15 per unit.

C.H. Kline, C.H. Kline & Company, Inc.: What is the estimated dollar volume of sealants sold per year? What types of products are included in this estimate?

Mr. LeFave: Some recent market research figures on elastomeric sealants that we've assembled show that they fall in a range of $5 to $7 million per year. This does not include the oil-base, or any of the standard nonelastomeric calking compounds. This includes the polysulfides, polyurethanes, acrylics, butyls, silicones, etc. We expect this will probably double in the next five years.

Unsigned question: Can epoxy resins be used as sealants in a temperature range of 70° F. to minus 30° F.?

Mr. Wittenwyler: Yes, but you'd have to select your compositon rather carefully to avoid sagging, and I also might qualify that by saying that joint or sealant shape design is very critical. Epoxies will remain flexible in this temperature range and, with proper joint design, they can be used successfully.

Mr. O'Hare: Can they *also be applied at temperature within that* range, and properly cured?

Mr. Wittenwyler: No. We don't know of any epoxy that will cure well below 50° F. This would be the lower temperature limit for application of epoxies.

Unsigned question: Is there any tendency of the one-part polysulfide to discolor stone? And if so, what type of primer do you recommend to prevent this?

Mr. LeFave: Yes, there is. It's quite slight, in the standard ASA tests on white cement. It stains at a relative humidity of about

95%. Over a period of seven days at 95% humidity, you'd probably get a one to three millimeter pink ring around the periphery of a dab of material on a piece of concrete. Therefore, as a company policy, we recommend primers be used. In fact, we practically demand that they be used. Our particular primer is a one-part polyurethane type with which we've had a number of years of experience, and it does prevent staining. It does a very good job under most conditions where these products are used.

Irvin Baker, Farboil Company: Can the one-part silicone joint sealants be applied as thin, high-temperature coatings?

Mr. Maneri: These sealants are generally designed for a particular application. The building sealant is not particularly designed to withstand temperatures of 500°, 700°, or 1000° F. for any period of time, as a thin or a thick coating. There are silicone sealants which will withstand a very wide range of temperatures, and there is very likely one which will be a good coating for the temperature range in which you are interested.

Unsigned question: What test data do you have to support the statement that adhesion of polyurethane sealants to glass is not greatly affected by ultra-violet exposure?

Mr. Fosgate: We have utilized the standard ASA tests where the reverse side of the glass is subjected to 96 hours of ultra-violet, then the panel is immersed in water for four days, and elongation and tensile studies are run. We lose approximately 25% of our ultimate tensile strength at the interface. The bond ruptures prior to rupture of the material, but this has been the failure in all test samples of our polyurethane. The bond ruptures first. The ultimate tensile strength of the urethane material itself is higher than the figures that we've quoted. We have approximately 165% elongation prior to rupture, and our gray material runs approximately 200% prior to rupture before exposure to sunlight.

Unsigned question: What Federal Specification covers the epoxy-polysulfide concrete bonding adhesive you mentioned?

Mr. Wittenwyler: It is the specification that was written by the Corps of Engineers, Ohio River Division Laboratories in Cincinnati. Federal Specification MMM-B-00350 Army (CE) covers an unfilled system, and Federal Specification MMM-G-00650 Army (CE) covers a filled system.

H.C. Kethman, Gas Purifying Materials Company, Inc.: Re one-component polysulfide sealants, are any problems encountered in production in regard to atmosphere control (temperature and relative humidity) in the mixing and milling area? Also, please comment regarding the moisture content of fillers.

Mr. LeFave: Yes, we've had a lot of trouble with this, but in the last ten months we've virtually eliminated it. We have accelerated quality control tests, so we can give fairly good delivery. Because of the stability, we've been able to maintain reasonable inventories. Our system, as I mentioned, is sophisticated but generally quite applicable. We have epoxies based on this system that we're thinking about producing, also polyurethanes. Because of our production experience, we don't anticipate any great problems with any of these. It's true, we've had difficulty with atmospheric humidity. The system is such that, at one phase, we have to maintain very tight controls, but it's quite easy to do.

Unsigned question: You mentioned pavement and step applications of the chlorosulfonated polyethylene material. Do you normally recommend this product for on-grade sealing problems?

Mr. Hilbush: No, we don't. Those applications were in locations where women's heels were not so apt to come in contact with the softer material. It was used on the back portion of the steps, and it was used up against the building wall, but this is not a standard recommended type of application.

Mr. O'Hare: Will this same material support mold or fungus growth?

Mr. Hilbush: Actually, the material itself does not support any mold, fungus, or mildew. In a few bathroom applications there were some evidences of mildew, but when we got right down to the crux of the problem, we found this was a result of soap film accumulating on the top of the coating or the sealant.

Richard Hall, The Sherwin-Williams Company: We have been unable to find any superiority for butyl rubber sealing compounds over the more conventional oil-base compounds. Is there some test method, other than actual exposure tests, that will show this material is better than others of similar price range?

Mr. FitzGerald: There are a number of test reports of laboratory evaluations, and there are qualitative expressions of opinion after close inspection of installed systems that give ample justification for the claims that are made for butyl-base systems or polyisobutylene-base systems with regard to their superiority over oil-base systems in terms of weather resistance, low temperature flexibility, and extended age in service. The laboratory comparative tests, of course, are accelerated tests, and they are the classical evaluation to which sealants are subjected. They again show quantitatively, in this case, advantages for material that remains permanently flexible, based on an elastomer such as butyl.

Harold F. Wakefield, Consultant: What do you mean by elastic memory, and where does it have significance in sealants?

Mr. Maneri: Although this may not be technically correct, the way I would define elastic memory is the ability of a sealant to return to its original shape, once it's been compressed for a given period of time, and perhaps under a variety of environmental conditions. Silicone rubber is well known for its low compression set, after being confined at higher temperatures. Thus, what I would describe as elastic memory for the purposes of this presentation is its ability to memorize where it was before it was compressed, and its ability to return to that state after it is released from a state of compression.

Unsigned question: You mentioned possible foaming when applying urethane sealants to a wet joint. What happens if it rains just after a joint has been completed?

Mr. Fosgate: You have to look at this two ways. First, if there's water or moisture in the joint, this will react with the urethane and produce a gas which causes foaming. We've had no problem with this, however. I remember one application when it rained about an hour after the joint was completed. What actually happens is that this cures up the immediate surface, and it skins over more rapidly. This protects the remainder of the sealant inside, so there is no noticeable foaming. I also mentioned that the surface tack is present for perhaps 24 to 30 hours. One trick for removing this surface tack earlier, if you must, is to wipe the surface with a little water or ammonia water. Actually, there's no problem if it rains after the sealant is in the joint. There would be a problem if water was coming out from inside the joint.

Unsigned question: Has there been any actual experience with the use of polyurethane sealants in highway expansion joints?

Mr. Fosgate: There have been a number of test installations of urethanes, particularly in the State of California, approximately two years ago. There were some 20 different types of sealants applied in an expansion joint on one of the California freeway system's bridges. As I recall, the joint at rest had an opening of approximately 1-1/2 in. It had to be able to compress to 3/4 in., and extend to 2 1/2 in. As of early in 1962, there were only two sealants in this installation which were still performing, and both of these were urethanes. In 1962, the State of New York published a report on an evaluation of sealants in highway expansion joints, but unfortunately, urethanes were not included in this study. However, at the end of 18 months, none of the sealants were still serviceable. I think this particular type of application warrants considerable study by sealant manufacturers. One of the unique properties of urethane is its resilience, and its ability to cast stones out as the joint closes. This can also be applied to an earlier question. Urethanes in grade joints will withstand the high spike heels of current design in women's shoes. They prove excellent in this type of application.

Mr. LeFave: We've been experimenting with urethane for approximately four and a half years, as far as the building industry goes. We've elected not to proceed with sealing of vertical joints or curtain walls, for our own reasons. We have, however, maintained one product which is used for horizontal joints. We've aimed it primarily at applications where there is a good deal of pedestrian traffic, such as shopping centers, Disneyland, etc. And, we have a continuous program on joint sealing, particularly with regard to bridge approach joints. These have proved reasonably successful. The failures have been cohesive failures -- splitting down the center. This can perhaps be taken care of by adjusting the modulus and the elongation. We've installed joints throughout the country. When we started about four and a half years ago, we had many failures. We still have some joints in Kansas that are in excellent shape. We also have some in the same areas Mr. Fosgate mentioned in California. About 90% of these are successful, and about 10% have cohesive splits down the center of the joint due to tortional movements of the joint, shear movements of the joint, shifting of foundations, etc. I personally feel that joint sealant technology cannot resolve these problems. I think the only way they might be resolved is with laminated prefabricated joints. Our metals division and our chemical division have this method under study right now. There has been work done in this field by several major companies with considerable success. Some of it has been published.

Unsigned question: Can coal tar-epoxy compounds be used as expansion joint sealants in both horizontal and vertical joints?

Mr. Wittenwyler: Yes, there would be no difficulty in thickening an epoxy-tar system to resist sagging and flowing. Normally though, epoxy-tar systems are not very elastomeric. Some other means would have to be incorporated to gain the distensibility that is needed. Thickening, however, is no problem.

Mr. O'Hare: Are there any flexible aliphatic epoxy resins available for use as joint sealants?

Mr. Wittenwyler: Normally, the epoxy resins are based on an aromatic bispheral structure. There are others which also have aliphatic, or straight-chain, hydrocarbon backbones. One would expect much more elongation and better hydrocarbon compatibility with these aliphatic types. To answer the question, there are several flexible, aliphatic epoxy resins on the market.

Unsigned question: What are the average elongation limitations for knife-grade or gun-grade high quality butyl sealing compounds?

Mr. FitzGerald: The upper limit would probably be 150% elongation with 100% at preferred range.

Unsigned question: News items tell of two-part butyl compounds being available in Europe. Are these compounds available in this country?

Mr. FitzGerald: If we think of a two-part system as a basic sealant with a curative agent, there are none in this country, and I question whether there are any in Europe. This might refer to some of the work that's done on the two-part chlorobutyl system which, because of its increased reactivity, is more amenable to curing at ambient temperatures. The work that we have done has been paralleled by work done in the laboratories of our English affiliate. It's possible that his was called butyl rather than chlorobutyl, and in that case, there is a decided possibility that this is in existence in Europe. If you're speaking of chlorobutyl, then I can say that in this country we have progressed to the extent that I described in my paper.

Unsigned question: In the use of butyl sealants as deep joint fillers, what happens to the solvent?

Mr. FitzGerald: Butyl is a high polymer, and it has a rather disturbing ability to hold solvent residues. I suspect that about 3% of the solvent is always retained in the sealant. Butyl rubber is also extremely impermeable, not only to water, but to the passage of other vapor. In regular rubber technology, this becomes a problem. If there is any vapor sealed in a butyl system, it has a slim chance of getting out by the regular mechanism of diffusion. In a deep joint, therefore, I think you would be risking some difficulty, providing the solvent content of the sealant was high, say in excess of 10%.

A.I. Tenzer, Tenzer Associates Inc.: Could you give us some data on the tear strength of the polyurethane sealant?

Mr. Fosgate: We have not run tear strength tests, as such, on our sealants. Some work has been done on the tear strength of urethane coatings, or coatings of a rubbery nature which are used in fabrics, such as linings of raincoats. The tear strength is very, very poor. In fact, once it starts to tear, there is no resistance. We have not run tear strength tests on the sealants system mainly because the tensile strength and the elongation are extremely high.

E.F. Reiher, Minnesota Mining & Manufacturing Company: You indicate that you are constantly upgrading chlorosulfonated polyethylene sealing material. How long do you test any new formulation on an actual building installation before you begin producing a revised version?

Mr. Hilbush: We have tried to run laboratory tests for about 12 months before we make any drastic changes. In some cases where the immediate tests, the weatherometer tests among others, show a need for tensile or adhesive improvement, this might indicate to us that we might want to change it much more rapidly. However, we try to resist this type of thing, and normally, I'd say 6 months is about the length of testing done. As for actual application in the field, this comes after laboratory testing. Usually, we run the tests in the lab and if they look good, then the chances are the product will be upgraded as we go along. You see, if we didn't do this type of thing, we probably would never have put the product into production in the first place, because of the poor shelf life that we encountered in the very early formulations.

Unsigned question: Do the current chlorosulfonated polyethylene sealants meet the Bureau of Standards specifications for elastomeric sealants?

Mr. Hilbush: They have not yet been tested for this particular application.

Unsigned question: How long a field performance record has now been established for one-part polysulfide sealants?

Mr. LeFave: From production materials, about a year and a half. Experimentally, about three and a half years, and even some simple, minor tests, about four years.

Mr. O'Hare: Are these all field tests, or basically lab tests?

Mr. LeFave: These are field tests.

Unsigned question: Do the one-component polysulfides perform satisfactorily at 50° F?

Mr. LeFave: Yes. In fact their extrusion rates are quite good at the lower temperatures, and even below freezing. They also cure at freezing temperatures, but very, very slowly. As the temperature rises, the rate of cure increases, as is the case with all systems of this type, since after all they are two-part systems, with the ingredients combined and inhibited so they can be accelerated by moisture from the air.

Mr. O'Hare: I think the other one you've already answered also, about the use of a primer on porous surfaces. You do recommend that?

Mr. LeFave: I do.

E.M. Newman, Hq. U.S. Air Force: You mentioned a government building where marble was the adherent. Please restate the name of this building.

Mr. Maneri: It is not a government building. It's the United Insurance Company of America Building in downtown Chicago, Illinois.

Unsigned question: Can silicone sealants be used successfully in concrete or ceramic tile-lined swimming pools?

Mr. Maneri: We have limited experience in this particular field, and I would have to say frankly we do not specifically recommend our sealants for this application. On the other hand, we do have a number of such installations which have been operating satisfactorily over the past year, or year and a half. Apparently, it is feasible according to some users.

N.C. Hanellin, Sonneborn Chemical & Refining Corporation: Would you kindly repeat the physical properties of one-part polysulfide under ASA 116.1.

Mr. LeFave: The ultimate hardness is 25 to 30 Shore A; ultimate elongation, 300 to 400%; tensile stress at 150% elongation is 30 to 35 psi; tensile strength ultimate is 100 to 125 psi; tear strength, 25 to 30 psi; adhesive strength and tensile shear (This is a single overlap of 1 sq. in.), 90 to 110 psi; and initial viscosity, if that's important, is 10,000 to 20,000 poise.

Question from audience: What are cure times?

Mr. LeFave: Cure times are a function of humidity and temperature. We arbitrarily took the samples off at 45 days. We have considerable evidence that they would have performed equally well at three weeks.

Dan Donovan, Larsen Products Corporation: Are epoxy sealants as critical of asphalt-oil coating as the polysulfide type of sealants?

Mr. Wittenwyler: Let me give you an example. We have an application of an epoxy-coal tar over portland cement. We've made similar applications over asphaltic concrete, which of course is rather low in asphalt content, about 8% by weight. These have been in use on the New Jersey Turnpike for about six years now, and they adhere very well. This is probably due to the low asphalt content, or the hard type of asphalt used on roads, as compared to that used on roofs. On roofs, I'm sure you would have good initial adhesion, but we don't have enough experience to recommend this use. We have good initial adhesion. A laboratory tensile test would result in failure in the asphalt, but I can't predict what effect time would have.

Mr. O'Hare: While we're still on the epoxy sealants, are there any toxic effects that might be attributed to the use of these sealants by the operators?

Mr. Wittenwyler: The level of toxicity is extremely low. I would like to add, though, that there are several different families of epoxies. Those we've chosen for sealants are among the least toxic. In addition to the epoxy resin itself, there is also a degree of toxicity involved with the curing materials, but again, the materials we've chosen have a very low level of toxicity. We would expect no difficulty in any application, providing reasonably good sanitary conditions are maintained, and providing the individual doesn't have a sensitivity or an allergy to materials of this type.

Unsigned question: What advantages, other than light color, does chlorosulfonated polyethylene have over neoprene for construction joint-sealing?

Mr. Hilbush: Other than color and a superior ability to withstand weather, I don't think it has any real advantages over neoprene. Longer life, I would say, is probably its biggest advantage.

John Talbott, Washington State University: Would the polyisobutylenes have promise as vibration-damping materials, if arranged to be strained in shear under vibrating loads?

Mr. FitzGerald: I'm not sufficiently informed to answer that question intelligently, at the moment. I'd be glad to delve into the question and get an answer for you.

Irvin Baker, Farboil Company: Can the solvent resistance of butyl sealants be improved?

Mr. FitzGerald: Butyl rubber is a hydrocarbon polymer, and it has no resistance to aliphatic or aromatic hydrocarbon. It has excellent resistance to oxygenated solvents and to some of the natural fats and oils. However, the resistance to the aliphatic and aromatic hydrocarbons cannot be improved. It is a basic characteristic of the polymer.

Unsigned question: You mentioned that a rapid cure system for polyurethane sealants applied by specialized equipment has been, or may be, developed. Would you please elaborate.

Mr. Fosgate: There are modified types of polyurethane sealants which are used in the assembly of clay pipes. This urethane sealant has a cure time on the order of 15 minutes. It's applied by special two-component equipment which mixes the parts A and B, as the material is applied. This type of equipment is not uncommon. The particular urethane sealant used in this operation is a well filled and very inexpensive sealant. The high performance sealants can be applied by the same techniques, so that they may be used, let's say, as road expansion-joint sealants, and rapidly applied by special equipment. They cure within a matter of minutes, so that you can drive traffic over the road on the same day or several days later. We feel that the particular systems that we're using at the present moment need a long pot life, and therefore are not suitable for such applications as roadways, where immediate traffic is desired.

Mr. LeFave: We supply such a clay-pipe sealant, and we have adapted it to traffic counters that cross highways, imbedded in a V-shaped groove in the highway. We also supply a variation of this material that has a one-minute pot-life. Traffic can run over it without wheel-pickup in five to seven minutes at normal temperatures. It's a very fast system that requires specialized application equipment. The quality of these materials is surprisingly high. They have excellent compression set, on the order of 1% at room temperature tested by ASTM compression set methods.

Arthur Scheller, The American Cyanamid Company: Is the excellent adhesion of the silicone sealant mostly mechanical rather than chemical, especially since silicones are noteworthy for their release properties, and in view of the difficulty of obtaining copper-clad or other metal-clad laminates?

Mr. Maneri: Our general feeling is that it is a combination of mechanical and chemical adhesion which takes place. The silicone joint sealants being marketed to the building trade are significantly different than silicones which are used in a variety of release applications. In fact, there is another particular silicone product on the market, which is a pressure-sensitive adhesive tape. So you can see that adhesion, per se, as well as release characteristics, can be introduced into the silicone formulation. It's a question of a blending of technology to get the particular properties which are desired in an application. To get back to the question, an example of why we feel it has to be a combination of chemical as well as mechanical attachment is its excellent, adhesion to glass, to which it is so chemically similar.

Mr. O'Hare: Can you give us a quick rundown on the modulus and elongation characteristics of the aged silicone sealants?

Mr. Maneri: Well, these vary somewhat with the size of the joint. At 100% elongation, the tensile strength runs in the neighborhood of 50 to 75 psi. At 150% elongation, the tensile strength would be 75 to 100 psi. This would be in a tensile bar about 1/8 in. to 1/4 in. thick. If the dimensions were greater, the tensile strength would be somewhat higher, perhaps 75 to 80 psi at 100% elongation, and 90 to 100 psi at 150% elongation.

E.F. Reiher, Minnesota Mining & Manufacturing Company: You mentioned a very low moisture vapor transmission rate for your sealant. What is the actual MVT value?

Mr. LeFave: Expressed as grams per square meter per mil for 24 hours, it would fall at about 500, or close to that range.

Mr. Reiher: And how does this compare with a conventional two-part polysulfide?

Mr. LeFave: This is about 50 to 150% lower.

Mr. Reiher: What is the actual test method used in determining these figures?

Mr. LeFave: We use an aluminum cup method with calcium chloride or some similar dessicant. We spread a film of about 50 mils across the surface and put it inside a dessicator at 50% relative humidity and 77° F.

Mr. Reiher: That's a standard ASTM test, I believe.

Mr. LeFave: Pretty close to it.

Arthur Scheller, The American Cyanamid Company: Would you care to comment on the use of oxiron-type resins in sealants, since these are, or could be, rubbers to begin with?

Mr. Wittenwyler: When they're cured as the manufacturer recommends, they have very, very low elongation, too low for sealant use. However, because of the rubber-like structure of the polymer, as you point out, it would probably be compatible with the butyl rubbers, and you could probably make an "alloy type" of sealant from it. This is just speculation, however. I really don't know.

James McClellan, Wyandotte Chemical Corporation: What is the effect of application temperatures in the 32° F. to 60° F. range on ultimate adhesion of polysulfide, chlorosulfonated polyethylene, silicone, and urethane sealants?

Mr. LeFave: I'll speak for the polysulfides, but let's limit it to the one-part polysulfides. At that temperature, the problem that usually exists is condensation on the surface in the form of a very, very thin film of moisture. If the sealant has sufficient attraction for that surface, that is, a specificity of attraction for that surface, it can preferentially displace the moisture and obtain a very good bond. We've had experience with this type of application, and feel no great degree of trepidation about it. Particularly if the primer, such as a urethane-base primer, has a high degree of water displacement ability, plus the fact that it also reacts with the water, and if there isn't very much on the surface, it can displace the water, and the result is a good bond. We don't see any great problem here. It can't be a wet surface, but let's say, a damp surface. The temperature presents a problem only insofar as it affects the rate of cure.

Mr. Hilbush: We've never found any severe problems with the chlorosulfonated polyethylenes. The only problem would be frost. If there is frost present, naturally there will not be a good bond. Low temperatures present no problems with this material, providing the surface is dry.

Mr. O'Hare: Will it have any effect on the rate of cure?

Mr. Hilbush: Well, of course, a low temperature always has a slowing effect. The cure is accelerated with heat. And, in fact, one of the ways that we considered of maintaining longer shelf-life was to take a page out of the polysulfide book, and refrigerate. But this, of course, presents other problems, so we abandoned that approach. Lower temperatures will definitely retard the cure.

Mr. Maneri: All other things being equal, I would say there would be absolutely no difference in application of silicone joint sealants in this temperature range. There might be a slight difference in cure rate, but it would be relatively insignificant.

Mr. O'Hare: You'd probably have some difference in cure rate, because at lower temperatures you normally don't have high humidity.

Mr. Maneri: The moisture content of the air would definitely have an effect. However, 32° to 60° F. is not a very wide range, and although the cure becomes rather steep between 55° and 60°, it should not be critical from a practical standpoint.

Mr. Fosgate: As long as there's no frost or moisture on the surface, the urethanes would not be affected. The time of cure would be somewhat longer, this being a time-temperature function, but there would be no effect on adhesion. In fact, I might even go so far as to say that the adhesion might be better because the material (and this is strictly a guess) would have a greater, or longer, period to thoroughly wet the surface.

Unsigned question: Is bond strength of chlorosulfonated polyethylene sealants to steel, aluminum, glass, and stone affected to any degree by one week's total water immersion?

Mr. Hilbush: This is one reason I mentioned the application involving the boat, and the application in concrete pools. As to steel, I don't know. This type of test has not been run.

Unsigned question: What test method do you use to measure erosion rate? You mentioned .0002 in. erosion per year.

Mr. Hilbush: What we've done is to use a standard aluminum cover over the bead of calk, and then this is strictly micrometer measurement. It's that simple. We go back every year and remeasure it.

Unsigned question: Do one-part polysulfides compare favorably with two-part compounds of similar quality on long-term, high temperature aging tests?

Mr. LeFave: The one-part system is decidedly superior.

A.I. Tenzer, Tenzer Company, Inc.: What data do you have on adhesion to glass and elastic recovery for the one-part material after 30 days' actual cure.

Mr. LeFave: Primarily the ASA specification in which, I think in all cases, it exceeds on recovery. And this is not 30 days, it is 40 days. However, we're quite convinced that 30 days would present no problem.

Appendixes

A Review of Specifications for Sealants

By Julian R. Panek, as a special assignment for the BRI Planning Committee on Adhesives and Sealants in Building

This is a review of specifications for sealants used for calking, glazing, and sealing, where the function of the sealant is to keep out weather and to maintain a seal. Specifications are also listed for sealants used in other applications where the sealants are required to adhere to various surfaces during movement over a wide temperature range. The list of specifications also covers sealants for aircraft integral wing tanks, for other aircraft components, for concrete highways, and miscellaneous sealant applications for protection against the weather. Many of the specifications are no longer active, but are listed for reference purposes.

SEALANTS FOR INTEGRAL FUEL TANKS

MIL-S-18336 -- Military Specification,[1] Dec. 10, 1954

Title: Sealing Compound, Water Dispersed, Fillet Type (for Integral Fuel Tanks).

Materials: Materials shall be a one-part sealing compound capable of being thinned with water. Requirements were met by a polysulfide water dispersion.

Description: Sealant is essentially putty grade consistency having at least 68% solids content which, upon drying, sets to a rubber-like product having resistance to aviation fuels, adhesion to aluminum, flexibility to -60° F. This specification is no longer being used, and was superceded by specification MIL-S-7502c.

MIL-S-5817a -- Military Specification, Aug. 12, 1952

Title: Sealant, Fuel Tank Polysulfide Polymer, Solvent-Type.

Materials: This specification covers the requirements for a solvent based polysulfide sealant used to seal integral fuel tanks. The thin film is then cured in the presence of ammonia gas.

Description: The system is desirable for sealing small, irregularly shaped fuel tanks after complete assembly of the wing.

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[1] Military Specifications may be obtained from the Navy Supply Depot, 5801 Tabor Road, Philadelphia 28, Pa.

The fill-drain method is used. The film is subsequently cured by subjecting the film to a environment of ammonia gas for 12 hours at ambient temperature at a pressure of 2 psi. The requirements for the film are quite similar to that for MIL-S-7502c.

MIL-S-7502c -- Military Specification, July 27, 1959

Title: Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion, Accelerator Required.

Materials: Sealant to be based on polysulfide liquid polymer with accelerator.

Description: This specification covers a polysulfide base compound for sealing and repairing integral fuel tanks and fuel cell cavities. The sealant requires a nitrile rubber topcoat conforming to MIL-S-4383. The use of the nitrile rubber cover coat keeps the absorption of fuel and extraction at a minimum to permit proper functioning of the sealant. This specification requires high adhesion and fuel resistance to Type III Reference Fuel. The sealant is required to maintain good adhesion at -65° F. to 140° F., be nonvolatile, remain flexible, and have low extractability.

MIL-S-8802b -- Military Specification, Oct. 21, 1958

Title: Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion.

Materials: Two-part sealant for sealing and repairing integral fuel tanks and fuel cell cavities.

Description: This is a more rigorous specification than MIL-S-7502c. Additional physical requirements have been imposed which include an elevated temperature solvent test and a heat aging cycle of seven days at 275° F. The jet fuel used has a more degrading effect than that used in MIL-S-7702c, and consequently, a more solvent-resistant sealant is required.

MIL-S-8784a -- Military Specification, April 3, 1958

Title: Sealing Compound, Aluminum Integral Fuel Tanks and Fuel Cell Cavities, Low Adhesion, Accelerator Required.

Materials: Sealant shall be based on polysulfide liquid polymer with accelerator.

Description: This specification covers a sealing compound having low adhesion for use as void fillers in integral fuel tanks and fuel cell cavities. The specification is very mild in its over-all requirements. Essentially, the compounds should strip easily and maximum adhesion shall not exceed two pounds. The sealant is dyed red so that it is never confused with other sealants. This compound does not require any adhesion additive, and is made using some white filler, along with a red dye. There are no problems expected meeting performance requirements with a lead dioxide cure.

SEALANTS FOR AIRCRAFT

MIL-S-7124 -- Military Specification, Feb. 13, 1951

Title: Sealing Compound, Pressure Cabin

Materials: Materials shall be a one-part or two-part elastomeric sealant. Materials are not specified.

Description: This specification covers a sealant for use in sealing pressure cabin seams, rivets, and faying surfaces for the purpose of making pressurized areas air-tight. The general requirements for the compound is that it adhere to aluminum, remain flexible down to -65° F., and be non-corrosive to aluminum in the presence of salt water. Simulated tests call for sealing a test panel in an assembly that is subjected to pressures and vibrations.

MIL-S-7126a -- Military Specification, Dec. 6, 1955

Title: Sealing Compound, Synthetic Glass

Materials: Sealing compound shall be of two types requiring elastomeric properties:

Type #1 - Putty-like material. Can be either a one- or two-part sealant.

Type #2 - Extruded tape.

Description: This specification covers the requirements of a sealant for use in sealing methyl methacrylate sheets into aluminum window assemblies for use on aircraft. The specification requires adhesion of the sealant to the acrylate sheet and the aluminum frame over various exposure environments, and that it be non-crazing. The sealant must remain flexible over a wide temperature range and must perform over a pressure gradient.

BUILDING SEALANTS (ELASTOMERIC)

ASA-116.1, 1960 -- American Standards Association Specification,[2] July 27, 1960

Title: Polysulfide Base Sealing Compound for the Building Trade

Materials: Polysulfide liquid polymer base sealing compounds.

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[2] American Standards Association Specifications may be obtained from the American Standards Association, Inc., 10 East 40th St., New York 16, N.Y.

Description: Specification covers performance requirements for polysulfide base sealing compounds used in joint sealing, calking, and glazing applications in buildings. Requirements cover minimum values of 10 psi and 100% elongation in specific test assemblies after original preparation, heat aging, water immersion, and low temperature cycling. Adhesion is required to aluminum, steel, glass, and concrete. Other tests include a staining test on both primer and sealant or masonry when used against stone.

TT-S-00227 -- Interim Federal Specification,[3] July 17, 1961

Title: Sealing Compound, Rubber Base, Two-Component (for Calking, Sealing, and Glazing in Building Construction).
Materials: Synthetic rubber base sealants.
Description: Specification covers the properties of two-component, cold-applied elastomeric synthetic rubber base joint sealing compound for sealing, calking or glazing application in buildings and other types of construction. Requirements for two classes of compounds call for a cured hardness range of 20 to 50, no staining to concrete or stone, as well as adhesion to cement, glass, and aluminum. Tests in assemblies call for cycling under various conditions of ambient temperature, 158° F., and 0° F., and for extension of up to 150% of original dimensions.

19-GP-3 -- Canadian Government Specification,[4] Jan. 23, 1959

Title: Compound, Calking and Glazing, Elastomeric, Chemical Curing Type, Gun Grade.
Materials: Elastomeric type sealing compound.
Description: Specification applies to a two-part elastomeric type sealant. Requirements call for cured sealants falling within a 10 to 60 Shore A hardness range. A unique test assembly of glass in an aluminum channel requires that the sealant used to seal the glass in the channel must perform satisfactorily after 500,000 flex-cycles over various environmental conditions from -10° F. to 160° F., and after water immersion and 77° F.

19-GP-9 -- Canadian Government Specification, March 1961

Title: Compound, Calking and Glazing, Elastomeric, Chemical Curing Type, Gun Grade, One-Component.
Materials: Elastomeric sealing compound.

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[3] Federal Specifications may be obtained from General Services Administration, Regional Office 3, Room 1643, Washington 25, D.C.

[4] Canadian Government Specifications may be obtained from the National Research Council, Ottawa, Canada.

Description: The specification covers requirements for a one-component sealant that cures to a rubbery compound. Maximum Shore A hardness of 45 is specified after 72 hours at 73° F. Test assemblies call for 500,000 cycles at -30° F., 77° F., 160° F., and water immersion. Low temperature flexibility is required at -65° F.

19-GP-5 -- Canadian Government Specification, Jan. 1962

Title: Compound, Calking, Elastomeric, Solvent Release Type, Gun Grade.

Materials: Elastomeric compound for calking interior and exterior wall panels and metal framework of buildings.

Description: A maximum Shore A hardness of 45 is required after 3 days. The compound shall have 20 lb. per inch adhesion, be flexible at -30° F., and exhibit weathering and ultraviolet light resistance. Shrinkage and solvent loss are not covered.

BUILDING SEALANTS (OIL-BASED)

TT-T-781a -- Federal Specification, July 12, 1941

Title: Putty and Elastic Compound; (for) Metal Sash Glazing.

Materials: A wide latitude in the choice of raw materials is allowed. Linseed oil and polyisopropylene are widely used.

Description: Two types of glazing compounds for interior and exterior exposure of metal sash are covered. Type I covers elastic glazing compounds, while Type II covers metal sash putty. The requirements are essentially for static applications in glazing and specify less than 2% weight loss after heat aging and adhesion properties to steel sash and glass.

TT-P-791a -- Federal Specification, July 20, 1943

Title: Putty-Pure-Linseed Oil (for) Wood Sash Glazing.

Materials: Materials cover linseed oil with either whiting or white lead and whiting fillers.

Description: This is a material specification covering two types of putties used for wood sash glazing. Certain handling properties are required.

TT-C-598 -- Federal Specification, April 25, 1942

Title: Compound, Calking, Plastic (for Masonry and other Structures).

Materials: A wide latitude in the choice of raw materials is allowed. Linseed oil and polyisopropylene are widely used.

Description: The general requirements are for a gun grade and knife grade calking compound which shall not shrink more than 20%; shall bond to glass, limestone, and wood. The materials are not required to follow movement in joints.

MIL-C-3923 -- Military Specification, Aug. 10, 1954

Title: Calking Compound.
Description: This specification covers minimum requirements for a permanently elastic, putty-like resin used in sealing joints between glass and metal frames.

MIL-C-18969b -- Military Specification, June 16, 1960

Title: Calking Compound, Metal Seam and Wood Seam.
Materials: The basic specification calls for a one package compound consisting of pigments thoroughly ground in a liquid vehicle.
Description: Requirements call for a gun grade and knife grade compound. Compound shall exhibit adhesion to steel; shall not sag when tested at 120° F., shall not bleed through white paint and is used essentially in static joints.

CONCRETE EXPANSION JOINT SEALANTS (ASPHALTIC TYPE)

SS-S-156 -- Federal Specification, Feb. 11, 1952

Title: Sealer, Cold-Application Emulsion Type, for Joints in Concrete.
Materials: No material is specified, probably an asphalt base in emulsion.
Description: Material shall be capable of being applied at temperatures up to 100° F., and is used to seal joints in concrete. Maximum water content is 32% and material is expected to give minimum performance in extension and adhesion.

SS-S-158a -- Federal Specification, Aug. 28, 1958

Title: Sealing Compound; Cold-Application, Ready-Mixed Liquified Type for Joints in Concrete.
Materials: Material not specified, but asphalt and various solvents and plasticizers are implied.
Description: Specification is similar to SS-S-156 in performance requirements, but is a solvent base rather than a water base sealer.

SS-S-159b -- Federal Specification, Aug. 28, 1958

Title: Sealing Compound, Cold-Application Mastic Multiple Component Type -- for Joints in Concrete.

Materials: Materials are not described, but dispersion of rubbery particles in second component may be the basis of causing gelation.

Description: Requirements are slightly more rigorous than for SS-S-156 and SS-S-158a, and material must give limited flow after cure and under test conditions.

SS-S-164 -- Federal Specification, Feb. 12, 1952

Title: Sealer, Hot-Poured Type, for Joints in Concrete.

Materials & Description: Asphaltic sealers are implied that will not flow from the joint or be picked up by tires at summer temperatures.

SS-S-167b -- Federal Specification, Dec. 17, 1958

Title: Sealing Compound, Jet Fuel Resistant Hot Applied, Concrete Paving.

Materials: Paving joint compounds may be based on asphalt, reclaimed rubber, resin and chemicals with or without limestone, sand, or vermiculite.

Description: The sealing compound shall be composed of materials that will form a resilient concrete joint filling compound having resistance to jet fuels and shall adhere throughout repeated cycles of expansion and contraction within a temperature range of 75° F. to 100° F.

SS-S-168 -- Federal Specification, March 25, 1955

Title: Sealing Compound, Sewer, Bituminous, Two-Component, Mineral-filled, Cold-Applied.

Description: The sealer shall be furnished in two parts: a liquid component consisting of asphalt blended with suitable plasticizing and fluxing oils; and a component consisting of natural asphalt and an inert mineral filler. The sealer, after mixing, shall exhibit certain adhesive requirements to concrete and shall exhibit chemical resistance to dilute acids.

SS-S-169 -- Federal Specification, April 20, 1954

Title: Seals, Joint, Sewer, Mineral-Filled, Hot-Pour

Materials: Aspahalt or coal tar based, with mineral filler.

Description: Joint-sealer compounds based on asphalt, coal tar or plastic soluble in CS_2, and inert mineral filler. Compounds must be free of water, shall not flow when heated to 350° F., and shall have chemical resistance to dilute HCl, NHO_3, H_2SO_4, KOH, and H_2S solutions. Three types are specified which cover five classes of compounds having a range of softening temperatures, varying from 180° F. to 270° F.

SS-S-170 -- Federal Specification, May 23, 1955

Title: Sealing Compound, Two-Component, Jet Fuel Resistant, Cold-Applied, Concrete Paving.
Materials: Material is not described, but polysulfide polymer implied from the description and requirements.
Description: More rigorous requirements for penetration, solubility and solvent resistance to RS-6 Fuel are given, along with flame resistance.

SS-S-171 -- Federal Specification, Dec. 4, 1951

Title: Sealer, Mineral-Filled Asphalt for Joints in Concrete.
Description: The joint sealer shall be hot-pour and will form a resilient and adhesive compound capable of sealing effectively joints in concrete pavements and structures.

CONCRETE EXPANSION JOINT SEALANTS (ELASTOMER MODIFIED)

SS-S-00200a -- Federal Specification, March 24, 1960

Title: Sealing Compound, Two-Component, Elastomeric Polymer Type, Jet-Fuel Resistant, Cold-Applied, Concrete Paving.
Materials: A two-component elastomeric polymer type compound having jet fuel resistance.
Description: A two-component sealant which, when mixed on the job site, shall permit traffic on pavement within one hour of application. The compound is used essentially on concrete expansion joints on highways and runways and requires good jet fuel resistance, flame resistance, resilience, and bond over a temperature range of -20° F. to +200° F. Flexural tests subject the sealant to 50% extension over various test conditions. The sealant cross-section is 1 in. x 3 in. x 2 in. in thickness in the various test assemblies.

SS-S-00195 -- Federal Specification, Aug. 15, 1961

Title: Sealing Compound, Two-Component, Elastomeric, Polymer-Type, Cold Applied, Cement Paving.
Materials: An elastomeric polymer base sealant.
Description: Same as SS-S-00200a and b, but not jet fuel resistant.

SS-S-00200b (Revision of SS-S-00200a) -- Federal Specification, Aug. 1, 1961

Title: Sealing Compound, Two-Component, Elastomeric, Polymer-Type Jet Fuel Resistant, Cold-Applied, Concrete Paving.

Materials: Jet Fuel resistant elastomeric polymer.

Description: A two-component sealing compound capable of being mixed on the job and cured so that traffic can be permitted within one hour without wheel-pickup. Certain requirements for viscosity are covered, as well as tackfree time and cure time. The sealant must meet rigid performance requirements in concrete test asssemblies wherein the sealant must be subjected to a 150% increase in thickness over the original thickness, while being cycled from -20° F. to 75° F. Test assemblies must be resistant to a 70/30 Isooctane/Toluene fuel by volume.

MISCELLANEOUS SEALANT SPECIFICATIONS

MIL-C-15705a -- Military Specification, Oct. 13, 1953

Title: Calking Compound (Liquid Polymer Polysulfide Synthetic Rubber; Formula No. 112 for Metal Closures).

Materials: The ingredients for Formula 112 are spelled out. The compound is based on liquid polysulfide polymer LP-2, made by the Thiokol Chemical Corporation.

Description: The compounds are based on a two-part compound and accelerator having approximately six hours working life and will set to a rubber in approximately three days. The calking compounds are to be used in seams, joints and dams formed between metal surfaces to provide water-tight and air-tight seals. The compound is not intended for use in calking moving joints or seams of wooden decks or hulls of vessels because of limited adhesion.

MIL-S-11030b -- Military Specification, July 28, 1954

Title: Sealing Compound, Non-curing Polysulfide Based.

Materials: Sealing compound shall be non-curing and based on a polysulfide polymer.

Description: The sealing compound is made at a relatively high viscosity and is generally applied by hand. Requirements call for less than 1.5% volatiles, less than 0.4% water solubility, no softening in mineral oil; shall not craze methyl methacrylate resins; shall be flexible to -65° F.; and shall not harden after 72 hours at 180° F. Material is used essentially to seal metal, glass, and polyacrylate plastics.

MIL-S-2869a -- Military Specification, Aug. 23, 1957

Title: Sealing Compound, Synthetic Rubber, Hose Cover Repair.

Materials: A two-part polysulfide that will adhere to fabric and neoprene hose cover. Primers are used as desired.

Description: The sealant is used to repair torn and abraded sections of large neoprene oil tanker hose. The repair must be rapid and the repair considerably lengthens the life of the hose by preventing water absorption into the fabric and subsequent rotting.

MIL-S-14231b -- Military Specification, Nov. 25, 1958

Title: Sealing Compound, Joint, Two-Component, for Bolted Aluminum or Steel Liquid Storage Tanks.
Materials: Materials used are a two-part polysulfide sealant.
Description: The sealant is a two-part polysulfide and is used to seal voids and joints between steel panels used in the preparation of bolted steel tanks. The sealant must adhere and resist various aviation fuels and remain flexible down to -65° F.

MIL-C-18255b -- Military Specification, Dec. 18, 1959

Title: Calking Compound, Synthetic Rubber Base, Wooden Deck Seal Application.
Materials: A two-part polysulfide sealant used to seal joints of flight decks constructed of Douglas fir and teak.
Description: The sealant shall adhere to the specific woods in spite of all weathering, and be capable of being extended 100% without adhesion failure. Various test assemblies are used in the testing procedures. Proper performance may require a primer.

MIL-C-22804 -- Military Specification, Feb. 15, 1961

Title: Cement, Sealing, Double Planking
Materials: Two-part polysulfide sealing compound used between double planking of wood and boat hulls.
Description: Cured compounds shall exhibit adhesion to Alaskan yellow cedar and Port Orford cedar, before and after heat aging, on water immersion and shall be capable of being extended 55% in particular test assemblies.

MIL-S-12158b -- Military Specification, Dec. 9, 1959

Title: Sealing Compound, Non-curing Polybutene.
Materials: The materials used in the sealer shall be polybutene base together with other materials to produce sealers suitable for flange, fording, packaging, ignition, and general purpose sealing.
Description: This specification covers mastic sealers for a variety of consistencies.

MIL-S-8516c -- Military Specification, Oct. 26, 1960

Title: Sealing Compound, Synthetic Rubber, Electrical Connectors and Electric Systems, Accelerator Required.

Materials: Specification covers accelerated organic polysulfide liquid polymers for the sealing and reinforcement of electric connectors, wiring, and other electrical apparatus and protection against corrosion or contamination.

Description: Specification calls for two grades of sealing falling between 30 and 60 Shore A hardness. Shrinkage limited to 12%, nonvolatiles shall be at least 94%, and requires adhesion to a variety of surfaces. Electrical resistance properties are high.

MIL-I-8860 -- Military Specification, Nov. 18, 1955

Title: Electrical Insulating and Sealing Compound.

Materials: Composition is not specified, but it has been found that substantial properties of silicone oils will generally be required to produce a compound meeting the requirements of this specification. The compound is effective in a temperature range of -65° F. to +400° F.

Description: A one-part non-curing compound is described. The sealing compound requires fair to good electrical resistance with non-corrosion to standard metals; shall not affect various plastic materials. The sealing compound is required to meet electrical requirements at 350° F.

Glossary of Terms for Adhesives, Coatings, and Sealants

By Joseph S. Amstock, as a special assignment for the BRI Planning Committee on Adhesives and Sealants in Building

A

ABRASION - The wearing away of a material surface by friction. Particles become detached by a combined cutting, shearing, and tearing action. Important factor in tire treads, soles, and conveyor belts.
Abrasion index - A value expressing abrasive resistance.
Abrasion tester - A machine for determining abrasion loss quantitatively.

ABRASIVES - Special mineral ingredients employed to impart abrasive power to rubber articles used for abrading, grinding, or polishing, such as rubber erasers and hard or soft rubber grinding wheels. Pumice, silica, tripoli, and carborundum are examples of abrasives.

ACCELERATE - To hasten or quicken the natural progress or process of a reaction or event. For example, the drying rate of an adhesive or sealer is hastened or accelerated by increasing the temperature. An accelerated test is usually a severe test that determines the comparative durability in a shorter length of time than required under service conditions.

ACCELERATED AGING - Any set of conditions designed to produce in a short time the results obtained under normal conditions of aging. In accelerated aging tests the usual factors considered are heat, light, and oxygen, either separately or combined. Sometimes called accelerated life. Most often accomplished by heating samples in an atmosphere of oxygen at 300 lb. per sq. in. pressure and 70°C. (Bierer-Davis), or by heating them in an oven provided with circulating air, maintained at 70° or 100°C. (Geer)

ACCELERATED WEATHERING - Machine made means of duplicating or reproducing weather conditions. Such tests are particularly useful in comparing a series of products at the same time. No real correlation between test data and actual service is known for the many resins and rubbers used in many products.

ACCELERATOR (of vulcanization) - Any substance which hastens the vulcanization of rubber causing it to take place in shorter time or at a lower temperature. In earlier days basic oxides such as lime, litharge, and magnesia, were recognized as having this function. Nowadays the important accelerators are organic substances containing either nitrogen or sulfur or both. According to potency, or speed of action, accelerators are sometimes classified as slow, medium, rapid, semi-ultra, and ultra-accelerators. Most accelerators enhance tensile properties, and many improve age resistance.

ACETONE - Dimethyl Ketone, CH_3-CO-CH_3. Used to extract most of the non-rubber constituents in natural rubber and also the free sulfur in vulcanizates.

ACETONE EXTRACT - In the analysis of rubber this represents the material soluble in and extractable by acetone. It includes free sulfur, fat acids, waxy hydrocarbons, resins, sterols, accelerators, and antioxidants, and also products resulting from the "perishing" of rubber.

ACETYLENE - The unsaturated hydrocarbon $HC \equiv CH$. It is a very reactive organic chemical. It is a colorless gas of garlic odor, d 0.91, mp -85° C, bp -83° C, slightly soluble in water and soluble in alcohol. Used as a chemical intermediate, as a heat source with oxygen in welding and metal cutting, and as an illuminating gas.

ACETYLENE BLACK - Carbon black made by the thermal decomposition of acetylene in furnaces. It is graphitic in nature and has high electrical conductivity. It is used in preparing electrically conducting rubber sheets.

ACID - Compound that contains hydrogen replaceable by metallic elements. When it attacks (reacts with) metal, hydrogen ions (H^+) are produced in solution. Acids turn litmus paper red, are usually sour tasting and react with alkalies to form a salt and water.

ACID NUMBER - An index figure designating a measure of the free fatty acids in animal and vegetable fats. It is the number of mg of KOH necessary to neutralize the free fatty acids in one gram of fat.

ACIDITY - The property of being acid or containing ionizable hydrogen. In more common language, the property of reddening litmus, or of combining with bases to form salts. The term is also used with reference to the quantity of acid substances present in any material, for example, naturally occurring organic acids in crude rubber.

ACRYLATE RESINS - Polymerization products of certain esters of acrylic acid and mathacrylic acid, as methyl and ethyl acrylate, possess great optical clarity and high degree of light transmission; nearest approach to an organic glass.

ACRYLONITRILE - Cyanoethylene, vinyl cyanide, $CH_2=CHCN$. A volatile liquid prepared by dehydration of ethylene cyanohydrin and by catalytic addition of hydrogen cyanide to acetylene. Used in copolymerization with butadiene in the manufacture of Buna N or nitrile rubbers.

ACTINIC LIGHT RAYS - Light rays consisting of the non-visible spectrum, consisting chiefly of infra-red and ultra-violet rays. In the U. S. actinic light rays are strongest in July, weakest in January. They usually cause a chemical change or have a deteriorating effect on films exposed to them for extended periods.

ACTIVATOR - A substance which by chemical interaction promotes a specific chemical action of a second substance. Most accelerators require activators to bring out their full effect in vulcanization (e.g., zinc oxide or other metallic oxides); some accelerators require a fat acid, expecially with zinc oxide.

ADDITION POLYMERIZATION - The small molecules (monomers) add together to form the polymer molecule. The polymer is usually linear. The subject is abbreviated sometimes to "A-polymerization."

ADHEREND - A body which is held to another body by an adhesive.

ADHESION - The clinging or sticking of two material surfaces to one another. In rubber parlance, the strength of the bond or union between two rubber surfaces or plies, cured or uncured. The bond between a cured rubber surface and a non-rubber surface, e.g. glass, metal, wood, fabric. (Note: The word "adhere" is an intransitive verb and should never be used as a transitive verb.)

ADHESION, MECHANICAL - Adhesion due to the physical interlocking of the adhesive with the base surface irregularities.

ADHESION OF RUBBER TO METAL - The strength of a bond formed between a metal surface and natural or synthetic rubber must be known regardless of the method used in obtaining the bond. Adhesion is expressed quantitatively as the tension per unit area required to cause a rupture of the rubber-to-metal bond. (ASTM Method D-429)

ADHESION, SPECIFIC - Adhesion due to valence forces at the adhesive-base surface interface. Such valence or attraction forces are of the same type that give rise to cohesion.

ADHESIVE - Substance capable of holding materials together by surface attachment. This is a general term that includes cement, glue, mucilage, paste, etc. Various descriptive adjectives are used with the term "adhesive" to indicate different types, such as:
Physical form: Liquid adhesive, tape adhesive, etc.
Composition: Resin adhesive, rubber adhesive, etc.
End use: Paper adhesive, label adhesive, etc.
Application: Sprayable adhesive, hot melt adhesive, etc.
Also see DRY SEAL ADHESIVE, PRESSURE SENSITIVE ADHESIVE.

ADHESIVE FAILURE - (1) The separation of the two surfaces with a force less than specified. (2) The separation of the two adjoining surfaces due to service conditions.

ADHESIVE, SETTING - Classifies the conditions to convert the adhesive from its packaged state to a more useful form.
Chemically setting: Requires addition of accelerator or catalyst to cure.
Cold setting: Sets at temperatures below 68° F (20° C)
Hot setting: Sets at temperatures above 212° F (100° C)
Intermediate temperature setting: Sets in the temperature range of 87-211° F (31-99° C)
Room temperature setting: Sets in the temperature range of 68-86° F (20-30° C)

ADSORPTION - The action of a body in condensing and holding gases, dyes, or other substances. The action is usually considered to take place only at or near the surface. Power of adsorption is one of the characteristic properties of matter in the colloidal state and is associated with surface energy phenomena of colloidally dispersed particles.

AGENT - See ANTI-CRACKING AGENTS, ANTI-CHECKING AGENTS, ANTI-FOAMING AGENTS, ANTI-FREEZING AGENTS, ANTI-GELLING AGENTS, BLOWING AGENT, BONDING AGENTS.

AGE RESISTANCE - Resistance aging by oxygen and ozone in the air, by heat and light. Antioxidants help, although there is no non-toxic substance against ozone for natural rubber, GR-S, neoprene, and nitrile rubbers.

AGGLOMERATION - The act or condition whereby minute particles dispersed in a liquid or viscous medium become united into larger groups.

AGING - A progressive change in the chemical and physical properties of rubber, especially vulcanized rubber, usually marked by deterioration. With natural rubber it is due primarily to oxidation and/or reversion; with GR-S it is due primarily to continued co-polymerization. May be retarded by the use of antioxidants. The verb is also used transitively to denote the setting aside of rubber goods under specified conditions for the purpose of observing their rate of deterioration (see SHELF AGING). Also see ACCELERATED AGING.

AGING TESTS - Accelerated tests of rubber specimens to find out their endurance by heating them in air, in air under pressure, or similarly in oxygen.

AIR BOMB - A pressure-resisting apparatus in which rubber may be aged rapidly in hot compressed air.

AIR-CURING - Vulcanization at ordinary room temperatures, or without the aid of heat.

AIR DRYING - A material is said to be air drying when it can be dried at ordinary room temperature without the use of artificial heat.

ALCOHOL - A hydrocarbon derivative in which one or more hydroxy (OH) groups have replaced a corresponding number of hydrogen atoms. Some of these are produced by fermentation while others are made synthetically. Ethyl grain is the best known and is commonly described as "alcohol." Commercial alcohol generally contains a denaturant to render it unfit for human consumption in order to minimize Federal taxation and regulation of its use. This solvent group is relatively expensive and is usually considered among the more harmless industrial solvents.

ALDEHYDE - Acetaldehyde, CH_3-CHO. Reacts with aniline to give an accelerator; one of the first known antioxidants.

ALIPHATIC - Organic compounds (hydrocarbons) in which carbon atoms are arranged in an open or straight chain. More commonly called napthas, they are prepared by straight-run, overhead distillation of petroleum. Familiar examples include gasoline, kerosene, paraffin, and natural gas. Aliphatic solvents are generally confined to reclaimed, natural GR-S, and butyl rubber formulas. Of the common solvents they are about the lowest in price and the least toxic.

ALKALI - Substance that neutralizes acids to form salt and water. Yields hydroxyl (OH-) ions in water solutions. Proton acceptor. Turns litmus paper blue.

ALKALINITY - The condition of having or containing hydroxyl (OH-) ions. Containing alkaline substances. The opposite of acidity. The property of turning red litmus blue, and of neutralizing acids to form salts.

ALLIGATORING - Term describing the appearance of a film that is cracked into large segments resembling the hide of the alligator. When alligatoring is fine and incomplete, it is usually called checking.

Alligatoring may be caused by one coat being applied over another before the bottom coat is thoroughly hard and dry and/or having the material skinning over so that the lower portion of the film is still soft and elastic, or by less elastic material being applied over a more elastic undercoating. When these conditions are present and the finished article is exposed to actinic rays or changes in temperature and moisture content, expansion or contraction of the film cracks the hard outer crust while the softer core gives without breaking.

With excessively heavy coats of rather dilute materials, this cracking of the outer crust can take place without temperature change by the shrinking action of the bottom portion -- much like clay mud is cracked under the summer sun.

Other causes of alligatoring include the too rapid evaporation of solvents or thinners and excessive air being forced into the film during spraying.

AMBIENT TEMPERATURE - The environment temperature surrounding the object under construction.

AMORPHOUS - Without crystalline structure.

AMPHOTERIC - Having the property of behaving as an acid or as a base according to the conditions of reaction. Zinc hydroxide is a well-known example; it dissolves in alkalies as well as in acids. Albumen is an example of an emphoteric organic colloid.

ANCHORAGE - Means of obtaining adhesion of rubber to rubber, rubber to fabric, rubber to metal, or rubber to other material.

ANGSTROM UNIT - The unit used to define the short wave-lengths of the electro-magnetic spectrum, such as light, ultraviolet light, and X-rays. One Angstrom unit = 10-8 centimeters = 0.1 millimicron = 1/250,000,000th of one inch.

ANHYDROUS - Term used to describe a compound or mixture which has lost all its water; in particular, water of crystallization or absorbed water.

ANHYDRIDE - Usually an acid from which water has been removed, practically or theoretically (e.g., acetic anhydride).

ANILINE POINT - The temperature at which a hydrocarbon solvent becomes miscible with an equal volume of anhydrous, chemically pure aniline. Often called the "critical solution temperature."

ANION - In solutions of electrolytes, the negatively charged ion which, during electrolysis, travels toward the positive electrode or anode. When rubber is electro-deposited from aqueous dispersions, the colloidal rubber particles behave as anions and deposit at the anode.

ANNEALING - Heating and slowly cooling to increase the ductility or remove internal stresses of metal or glass.

ANODE - The positive electrode in a solution of electrolytes (or in a vacuum tube) at which electrons leave the solution and at which oxidation occurs. It is also the negative pole of a battery.

ANTI-CHECKING AGENTS - Antioxidants are good for this purpose. Also petroleum waxes that bloom out and absorb ultraviolet light.

ANTICOAGULANT - A substance which prevents the coagulation of a colloid suspension or emulsion. Rubber latex coagulates spontaneously after tapping, due to bacterial action. On the plantation the most commonly used agent is ammonia. However, formaldehyde and ammonia, sodium sulfite, or caustic soda may also be used. Today the use of commercial bactericides is on the increase. Also called stabilizer and latex-preservative.

ANTI-CRACKING AGENTS - Softening agents are usually anti-cracking agents. Some antioxidants work well also. Chiefly a good vulcanizate resists cracking; high tensile, high tear resistance, high resilience, and good resistance to heat aging.

ANTI-FOAM - An additive used to reduce foaming tendencies particularly in products applied by roller coating equipment. Its function is to increase surface tension.

ANTI-FOAMING AGENTS - Long chain saturated alcohols, $C_6H_{13}OH$ to $C_{18}H_{37}OH$. Dodecyl alcohol, $C_{12}H_{25}OH$, is a very good agent.

ANTI-FOULING PAINT - The last coat of paint applied to the hull of a ship or other surfaces which is exposed to sea water. Contains toxic substances, such as red or yellow mercuric oxides or red cuprous oxide. These toxic substances prevent the attachment of barnacles and other marine growths.

ANTI-FREEZING AGENT - A substance added to water to lower the freezing point of the solution. Methanol is added to emulsion systems for polymerizations at temperatures close to or below freezing.

ANTI-GELLING AGENTS - Ammonium hydroxide and other basic substances are anti-gelling agents of latex.

ANTIOXIDANT - Usually organic and nitrogenous. A substance which inhibits or retards oxidation and certain other kinds of aging. Some antioxidants cause staining or discoloration of the rubber compound on exposure to light and are used only in black or dark colored compounds. Others (phenolic), described as non-staining, are used in white or light-colored compounds.

APPLICATION - Term describing the act of going over the entire area to be coated or sealed only once. For example, when the operator spray-coats the entire surface without repetition, he has made one application. If he immediately goes over the same work again, he has made another application.

For adhesives and coatings the principal methods of application are brushing, spraying, dipping, stenciling, flowing, stamp-padding, roll-coating, knife-coating, squeegeeing, spatula, and notched trowel.

For sealers the principal methods of application are spatula, calking gun, flow gun, pressure extrusion units, and spray gun.

ARC RESISTANCE - Resistance of rubber to an electric arc. In making the test, point electrodes are placed on two points of the same surface and an arc is then passed between the electrodes. As the current is increased, the rubber eventually breaks down and the arc travels on its surface.

ARO CLOR - A chlorinated diphenyl plasticizer.

AROMATIC - This term refers to chemical compounds that are derivatives of benzene.

ASBESTINE - An inert pigment or extender consisting of a fibrous variety of talc (magnesium silicate). It aids in preventing settling of pigments and adds strength to dried coating films.

ASBESTOS - A fibrous mineral from which fine fibers of appreciable length may be separated.

ASH - The residue of mineral matter left when raw or vulcanized rubber is burned. Does not always represent original mineral ingredients. Carbonates and sulfides may be changed to oxides. Lead and antimony compounds may be volatilized. Silicates may interact with other substances. Gives only approximate indication of composition of the rubber ashed.

ASPHALT - Naturally occurring solid or semi-solid mineral pitch or bitumen, more or less soluble in carbon disulfide, naphtha, and turpentine, and fusible at varying temperatures. Gilsonite, glance-pitch, manjak, Grahamite, and Trinidad pitch are examples. Also bituminous residues left from the distillation of petroleum or coal tar.

ASPHALTUM - A mineral-like material that is mined much like coal and has somewhat the same general appearance. It is soluble in oil, petroleum and coal tar hydrocarbons, and many other solvents.

ASSEMBLY TIME - The time interval (either necessary or permissible) between spreading the adhesive to either or both surfaces (adherends) and the application of pressure and/or heat to the assembly.

ASSEMBLY TIME, CLOSED - The interval between completing the assembly and application of pressure and/or heat.

ASSEMBLY TIME,OPEN - The optimum interval between spreading the adhesive on the adherend and completion of the assembly for bonding.

ATMOSPHERIC PRESSURE - The pressure of air at sea level exerted equally in all directions. The standard pressure is that at which the mercury stands at 760mm (14.7 lb. per square inch).

ATMOSPHERIC OR OZONE CRACKING - A fissured surface condition which develops on stretched rubber exposed to the atmosphere or to ozonized air. When the fissures are minute, the condition is called checking.

ATOMIC NUMBER - The number indicating the location of an element in the periodic table. (Hydrogen is 1, carbon 12, oxygen 16, and uranium 92.)

ATOMIC WEIGHT - Relative weight of an atom of an element as compared with the weight of one atom of oxygen taken as 16.

AUTO IGNITION POINT - The temperature at which solvent vapor and air mixtures will ignite without the aid of a spark or flame.

B

BAKING - The process of drying a material by application of artificial heat. A baking-type product requires this heat to become hard and dry. Certain enamels are of this type.

BALL MILL - A cylindrical metallic or ceramic mill which employs metal or ceramic balls or stones inside the revolving cylinder. The balls or stones break down agglomerates of pigment particles and in some cases reduce the unit particle size by falling against each other and against the side of the cylinder. Such mills may or may not be lined.

BASE - Any substance, organic or inorganic, having an alkaline character or the ability to combine with or neutralize an acid.

BEAM (Naval) - Greatest width of the ship.

BEATER-PROCESS PAPER - Paper in which most or all of the binder (generally rubber) is added to the fibers before the sheet is formed on a paper machine.

BEND TEST - A means of testing the flexibility of a compound at a specified temperature. The compound is applied to metal, dried or cured, and, after conditioning at the specific temperature, bent over a mandrel to determine the product's resistance to rupture.

BENZENE - A hydrocarbon of the composition C_6H_6; the initial member of the aromatic or benzene series. Its molecular structure is conceived as a six sided ring with double linkages between each alternating pair of carbon atoms and a hydrogen atom attached to each carbon. It is obtained commercially by the distillation of the light oils produced from coal tar. It is considered very toxic. Benzol is an industrial (less pure) grade of benzene. Toluene and xylene are related, less toxic compounds.

BINDER - Component of an adhesive or coating composition which is primarily responsible for the adhesive forces which hold two bodies together.

BITUMEN - Originally, mineral pitch or asphalt. Now, any of a number of flammable mineral substances, consisting mainly of hydrocarbons, including the hard, brittle varieties of asphalt, the semi-solid maltha and mineral tars, the oily petroleum, and even the volatile naphthas.

BLACK - A term referring to the several types of carbon black utilized in the rubber industry and also to the absence of color. Zero brilliance and 100% saturation of light waves.

BLEEDING - Migration to the surface of plasticizers, waxes, or similar materials to form a film or beads. Also see BLOOM.

BLENDING - A step in reclaiming in which the devulcanized stock is mixed with reinforcing and processing agents prior to refining.

BLISTERING - The forming of pockets of air or gas trapped within an elastomeric vulcanizate.

BLOCKING - Undesired adhesion between touching layers of a material, such as occurs under moderate pressure during storage or use.

BLOOM - A discoloration or change in appearance of the surface of a rubber product caused by the migration of a liquid or solid to the surface. Examples are sulfur bloom and wax bloom. Not to be confused with dust on the surface from external sources.

BLOWING - Porosity or sponginess occurring during cure. In latex goods, a permanent deformation caused when the deposit leaves the form during curing or drying.

BLOWING AGENT - A substance such as sodium bicarbonate or a nitrogen releasing agent added to a rubber mix to produce gas during vulcanization, thereby bringing about a cellular or sponge-like structure.

BLOWN OILS - Semi-solid or petroleum derivatives produced primarily through the action of air upon the originally fluid native bitumens which are heated during the blowing process. Oils which have had air blown through them to increase their viscosity or to alter other properties.

BLUSH - See BLOOM. Also whitish surface appearance where moisture has condensed before solvent is all evaporated.

BOILING POINT - The temperature at which the vapor pressure of a liquid is equal to the pressure of the atmosphere.

BOILING RANGE - The thermometer-indicated range within which a liquid boils to dryness.

BOMB - A heavily constructed, pressure-resisting, steel vessel with bolted, gas-tight cover, in which rubber or other material is exposed to oxygen or air under high pressure for accelerated aging. For maintenance of desired temperature, the bomb is placed in a water or air bath.

BOND (Noun) - (1) The attachment at the interface between an adhesive and an adherend. See also ADHESION, JOINT. (2) A coat of finishing material used to improve the adherence of succeeding coats.

BOND (Verb) - To join materials together with adhesives. To adhere.

BONDERIZE - A treatment for iron and steel in which the surface is converted to an insoluble phosphate. It has little corrosion resistance in itself but provides an excellent base for paints.

BONDING AGENTS - Substances or mixtures of substances that are used for attaching rubber to metal. Generally the rubber compound is vulcanized by heat in the process. Cyclized rubber or rubber isomers, halogenated rubber, rubber hydrochloride, the reaction products of natural rubber and acrylonitrile, polymers containing diisocyanates, are all used.

BONDING RANGE - The optimum time interval after applying the adhesive until surfaces should be joined together. This is also called the open assembly time.

BOND STRENGTH - The force per unit area or length necessary to rupture a bond. See also TENSILE TEST, SHEAR TEST, PEEL-BACK TEST and CLEAVAGE.

BOOTTOPPING AREA - That area on the exterior of a vessel extending from the light load water line to six inches above the full load water line.

BOW - Depression in surface. Also, curve or displacement in filling threads in fabric.

BREAKDOWN - To soften or plasticize rubber by working it on a mixing mill or in an internal mixer. Breaking down precedes the incorporation of compounding ingredients in mixing. To mill or to masticate.

BREAKDOWN TEST (Electrical) - The process of determining the potential difference at which dielectrics or nonconductors such as wire insulation or electricians' gloves break down or puncture.

BREAKDOWN VOLTAGE - The potential required to puncture the dielectric when the electrodes are in contact with the material and the voltage is increased at a specified rate. Also see ELECTRICAL BREAKDOWN.

BREAKING - Coagulation of the solid matter of a dispersion, resulting in film formation and adhesive strength. In practice, breaking is accomplished by applying pressure on the bond.

Fast-breaking refers to dispersions that are easily coagulated by light pressure.

Slow-breaking refers to dispersions that do not coagulate under light pressure.

Breaking also can occur when water dispersions are frozen. The resulting material is generally unusable.

BRILLIANCY - The brightness or apparent strength of a color to the eye is its brilliancy. This attribute of color corresponds to the loudness of sound. Brilliancy is also used to describe a glittering surface. For example, a very high lustre is sometimes spoken of as a brilliant lustre. A white article approaches 100% in brilliance while a jet black approaches zero.

BRITTLENESS - Tendency to crack or snap when subjected to deformation.

BRITTLE POINT OR BRITTLENESS TEMPERATURE - The temperature at which a rubber test strip attached to a rapidly rotating disc and gradually cooled breaks in two. The kind of rubber and state of vulcanization both influence brittle point. (See ASTM Method D-746.)

BROOKFIELD SYNCHRO-LECTRIC VISCOSIMETER - A portable form of the rotating cylinder apparatus for the viscosity of latex.

BTU - British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

BUFFER SOLUTION - A solution containing a weak acid together with a salt of a weak acid, or a weak base together with a salt of a weak base, and capable of neutralizing (within limits) both acids and bases added to it. Such solutions resist change in their hydrogen ion concentration on the addition of acid or alkali, a phenomenon known as buffer action.

BULKING VALUE - The solid volume of a unit weight of material, usually expressed as gallons per pound but also expressed inversely as pounds per solid gallon. For practical purposes the latter value is 8.33 multiplied by the specific gravity. See SPECIFIC GRAVITY.

BUNA N - The German emulsion copolymer of 75 parts of butadiene and 25 parts of acrylonitrile. It is heat and weather resistant, and especially resistant to the swelling action of oils, solvents, and greases. Increase in the proportion of acrylonitrile increases the swelling resistance. Buna N was manufactured in this country during World War II under the title of GR-A. The four large rubber companies manufacture it with the names Hycar OR (Goodrich); Chemigum N (Goodyear); Butaprene N (Firestone), and Paracril (formerly Perbunan) (U.S. Rubber). These synthetic rubbers are known in general as NITRILE RUBBERS.

BUNA S - The German name for the emulsion copolymer of 75 parts of butadiene and 25 parts of styrene, at about 50° C. (122° F.) In this country, during World War II and after, it was manufactured somewhat similarly and given the name GR-S.

BUTADIENE - $CH_2=CH=CH=CH_2$. A gaseous hydrocarbon of the diolefin series, boiling at -5° C. Also known as erythrene, divinyl, pyrollylene. Polymerizable to a synthetic rubber, polybutadiene. Butadiene is the chief raw material for making the synthetic rubbers of today. Copolymerized with styrene it yields GR-S; with acrylonitrile the various Buna N or nitrile synthetic rubbers are obtained.

BUTALASTIC - A word serving as a contraction of the name of a commercial group of interpolymers called "synthetic butadiene elastics."

BUTAPRENE - Now called Paracril. See BUNA N.

BUTAPRENE N - Modified butadiene-acrylonitrile copolymers (Firestone Tire and Rubber Company). See BUNA N.

BUTTERING - A method of mastic application; as butter is spread on a piece of toast.

BUTYL RUBBER - A copolymer of about 98% isobutylene and 2% isoprene. It has the poorest resistance to petroleum oils and gasolines of any rubber. Excellent resistance to vegetable and mineral oils; to solvents such as acetone, alcohol, phenol and ethylene glycol; and to water and gas absorption. Heat resistance is above average. Sunlight resistance is excellent. Its abrasion resistance is not as good as natural rubber. Usually low permeability to gases.

C

CALCITE - Calcium carbonate, $CaCO_3$.

CALENDER - A machine equipped with three (or more) heavy, internally heated or cooled rolls revolving in opposite directions, and used for continuously sheeting or plying up rubber compound, and frictioning or coating fabric with rubber compound.

CALKING - The process of sealing a joint or the materials used. Most often refers to linseed oil and lead compounds and to cotton or oakum strands used in back of seams rather than to the more recently developed sealing materials.

CALORIE - The quantity of heat necessary to change the temperature of one gram of water from 3.5° C to 4.5° C. This is a small calorie.

CAOUTCHOUC - The French word for crude rubber. Has been used by some writers to designate the purified rubber substance which is referred to most generally as rubber or rubber hydrocarbon. Generally supposed to be derived from South American Indian, "Caa-o-chu," meaning "weeping tree." In German, "Kautschuk."

CAPACITANCE - The amount of electrical energy that can be stored by a condenser. It is a function of the voltage applied, the area of the plates, the thickness of the dielectric, and the dielectric constant. The unit of capacitance is the farad (f).

CAPILLARITY - The peculiar action by which the surface of a liquid is elevated or depressed where it is in contact with a solid (as in a tube). It depends on the relative attraction of the molecules of the liquid for each other and those of the solid.

CARBOHYDRATE - A large group of organic compounds composed of carbon, hydrogen and oxygen, and having the hydrogen and oxygen present in the same ratio as in water (H_2O), from which fact the name is derived. They include the sugars, starches, and celluloses and, for the most part, are derived from the vegetable kingdom. As a group they are characterized by emitting the odor of burnt sugar when heated.

CARBON BLACK - Finely divided carbon formed by the incomplete combustion of natural gas; the carbon deposited on moving channel irons (channel carbon black); and the carbon formed by the incomplete combustion of natural gas or petroleum in large closed furnaces (furnace carbon black). These carbon blacks are used in tread compounds because they are reinforcing agents and increase the abrasion and tear resistance. Channel black reduces the resilience of rubber compounds.

HPC - Hard processing channel
MPC - Medium processing channel
EPC - Easy processing channel
CC - Conductive channel
HAF - High abrasion furnace
HMF - High modulus furnace
SRF - Semi-reinforcing furnace
RF - Reinforcing furnace
CF - Conductive furnace
FF - Fine furnace
VFF - Very fine furnace
FEF - Fast extruding furnace
FT - Fine thermal
MT - Medium thermal

CARBON GEL - An intimate structure formed between rubber and certain fine particle size carbon blacks under proper elevated temperatures during mixing, measurable by a decrease in benzene extract. Characterized by complete insolubility in benzene.

CARNAUBA WAX - A hard wax obtained by threshing the fronds of the Carnauba palm (Copernicia cerifara) of Brazil. Density (15° C): 0.990-0.999. Melting point: 80-86° C. Contains 54-55% of unsaponifiable (hydrocarbon) matter. Used in making varnishes, floor waxes, shoe polishes, phonograph records, and to some extent in certain rubber compounds.

CASEIN PLASTICS - Horn-like substances obtained from casein, the chief protein found in milk, hardened through the action of formaldehyde or some other agent, and seasoned by drying.

CATALYSIS - The action of any substance which, without itself undergoing apparent chemical change, initiates, accelerates, or inhibits a chemical reaction.

CATALYST - Substance which markedly speeds up the cure of an adhesive when added in minor quantity as compared to the amounts of primary reactants.

CAUSTIC EMBRITTLEMENT - Embrittlement of a metal resulting from contact with an alkaline solution.

CELLULAR RUBBER - Cellular rubber products all contain cells or small hollow receptacles. The cells may either be open and interconnecting or closed and not interconnecting. (Reference: ASTM Specification and Method D-1056)

CELLULOSE - A carbohydrate, $(C_6H_{10}O_5)X$, as the chief component of the cell walls of plants. Upon hydrolysis it yields glucose. Strictly, it is a polysaccharide consisting of glucose anhydride units bonded together through the 1 and 4 carbon atoms with B-glucosidal linkages.

CELLULOSE ACETATE - Cellulose acetate itself is made by treating cotton linters with acetic acid and acetic anhydride in the presence of a catalyst such as sulfuric acid. Both chemical and physical processes are involved in the manufacture of cellulose acetate plastics. They are not pure chemical compounds, but rather "solid" or colloidal solutions of cellulose acetate in plasticizers.

CEMENT - A dispersion of "solution" of unvulcanized rubber compound in a suitable solvent such as petroleum naphtha or aromatic hydrocarbons. Cements are also made from latex or water dispersions with or without the addition of organic solvents.

CENTIPOISE - 1/100 of a poise which is a value for viscosity. The viscosity of water at 20° C is approximately 1 centipoise.

$$\text{Millipoise} = 1/1000 \text{ poise}$$

$$\frac{\text{Millipoises}}{10_d{}^t} = \text{centist}$$

where d^t = density of a substance at the same temperature t.

CENTISTOKE - 1/100 of a stoke, which is the unit of kinematic viscosity.

CHAIN THEORY OF POLYMERIZATION - Chains are formed in the preparation of polymers by the 1,2-addition of vinyl radicals and the 1,4-addition of butadiene and its derivatives. Branched chains are believed to be difficult to prepare.

CHAINS, STRAIGHT, BRANCHED - Polymer chains are chiefly straight; there are small branches of phenyl groups in GR-S and polystyrene, and of ethylene (vinyl) from 1, 2-addition of butadiene in polybutadiene and in GR-S. It is difficult to prepare polymers with large branched chains.

CHALKING - Formation of a powdery surface condition caused by disintegration of surface binder or elastomer due to weathering or other destructive environments.

CHANNEL BLACK - A form of carbon black made from natural gas by the channel combustion process. The gas is burned with insufficient air in jets, the flames from which are allowed to impinge on a cool metallic surface (channel) from which the deposited carbon is scraped. For many years it was the best reinforcing agent for natural rubber and made it highly abrasion resistant. Also see CARBON BLACK.

CHECKING - The development of slight breaks in a coating which do not penetrate to the underlying surface. Checking may be described as visible (as seen by the naked eye) or as microscopic (as seen under magnification of 10 diameters). Also see ANTI-CHECKING AGENTS.

CHECKING, SUNLIGHT - The development of minute surface fissures as a result of exposing rubber articles to sunlight, generally accelerated by bending or stretching.

CHEMICAL RESISTANCE - The resistance offered by elastomer products to physical or chemical reactions as a result of contact with or immersion in various solvents, acids, alkalies, salts, etc.

CHINA CLAY - Kaolin, hydrated aluminum silicate, $Al_2O_3.2SiO_2.2H_2O$.

CHLORINATED HYDROCARBONS - Organic compounds in which one or more of the hydrogen atoms have been replaced with chlorine. They are generally used in polysulfide formulas. They are fairly high in price although their toxicity is the main reason for their limited usefulness. In general, they are not very flammable and some do not burn at all. In fact, some are used as fire extinguishers.

CHLORINATED RUBBER - When chlorine is passed into a solution of crude rubber, substitution as well as addition of chlorine takes place and a white fibrous product of the approximate formula $(C_{10}H_{13}Cl_7)X$ is obtained. Soluble in benzene, chloroform, and acetone.

Solutions on evaporation leave a tough transparent film very resistant to concentrated sulfuric, nitric, and chromic acids. A component of certain rubber to metal adhesives.

CHLOROPRENE - 2-Chloro-1, 3-butadiene, a volatile, colorless liquid which boils at 59°C, synthesized from acetylene. It is used in the manufacture of neoprene, which is obtained by polymerizing chloroprene under suitable conditions.

CHROMATIC SCALE - The colors of the spectrum arranged in the order of wave length ranges as shown in millimicrons.

CHURN - (1) A vessel in which rubber compounds are stirred into solvents. (2) To stir or mix.

CLAY - Any naturally occurring mineral substance consisting preponderantly of hydrous aluminum silicates, which when finely divided and mixed with water, yields a more or less plastic mass which can be formed and molded, and which will retain its shape on drying. Clays vary greatly in composition but in their purest forms they approach the composition of Kaolinite, $Al_2O_3.2SiO_2.2H_2O$. They are used as compounding ingredients in rubber, some of them having mild reinforcing properties.

CLEAVAGE - A method of rupturing adhesive bonds between rigid materials, best described as a prying action.

COAT, DOUBLE - Generally applies to two successive coats applied to one surface. In spraying, it means to spray first a single coat with vertical strokes and then across with horizontal strokes, or vice versa. In the woodworking industry the term means one coat applied to each of the two mating surfaces. In adhesives and coatings, the term means a single coat applied to each surface.

COAT, SINGLE - One layer of applied material on a surface, whether applied by brush, spray gun, flow gun, etc. In spray jargon, it means two strokes of the gun, the first down and second up, or the first to the right and the second to the left. The second stroke should cover the first completely. The third and fourth strokes should cover 1/2 of the first two, while the fifth and sixth should cover 1/2 of the third and fourth, etc. See COAT, DOUBLE.

COATING - A material, usually liquid, used to form a covering film over a surface. Its function is to decorate and/or protect the surface from destructive agents or environments (abrasion, chemical action, solvents, corrosion, and weathering).

COC - Cleveland Open Cup, an instrument and test method used to determine flash points of solvents and, more commonly, of compounded materials (adhesives, coatings, sealers, etc.).

COEFFICIENT OF ELASTICITY - If a strip of rubber of length l and cross section q is elongated by an amount l when loaded with a weight p, the relation between these quantities according to Hooke's law is:

$$\Delta l = a\left(\frac{l\,p}{q}\right) \text{ or in differential form } dl = a\left(\frac{l\,dp}{q}\right)$$

The proportionality factor a is known as the coefficient of elasticity. If l is measured in meters, q in square millimeters and p in kilograms, the coefficient of elasticity thus defined is obviously equal to the elongation that is produced in a strip one meter long and one square millimeter in cross section by a load of one kilogram.

COEFFICIENT OF EXPANSION - The coefficient of linear expansion is the ratio of the change in length per degree to the length at 0°C. The coefficient of surface expansion is two times the linear coefficient. The coefficient of volume expansion (for solids) is three times the linear coefficient. The coefficient of volume expansion for liquids is the ratio of the change in volume per degree to the volume at 0°C.

COHESION - That form of attraction by which the particles of a body are held together usually by primary or secondary valence forces. The internal strength of film.

COLD FLEXIBILITY - Flexibility following exposure to a predetermined low temperature for a predetermined time.

COLD FLOW - The permanent deformation under constant stress. Also defined as the continuing dimensional change under static load that follows initial instantaneous deformation. If subjected to pressure long enough, no organic material will return exactly to its original shape. Compression set is the amount by which a small cylinder fails to return. See also CREEP.

COLD PRESSING - Bonding operation in which an assembly is subjected to pressure without the application of heat.

COLD RESISTANT - Withstands the effect of cold or low temperatures without loss of serviceability.

COLD RUBBER - GR-S polymerized at a temperature of 5° C.(41° F.) or lower. Cold-polymerized rubbers generally show improved physical properties such as abrasion resistance, over rubbers polymerized at 50° C. (122° F.)

COLOR - A property or quality of the visible phenomena distinct from form and from light and shade, depending on the effect of different wave lengths on the retina of the eye. The term color is sometimes used inaccurately to denote hue, tint, shade, pigment, dyestuff, etc.

COMPATIBILITY - Ability of two or more substances to mix or blend without separation or reaction.

COMPRESSIBILITY - The resistance offered by substances to high pressure. Natural rubber has extremely small cubic compressibility when pressure is applied to masses which are entirely confined. If a compressive force acts on rubber which is free to be displaced in any direction, it will undergo elastic deformation, storing up its applied energy and returning some of it when the force is removed, the difference being dissipated as heat. Be cause of this behavior, rubber has found wide use for damping vibration and absorbing shocks, as in mountings for motors and other machinery, cushions for impact hammers, railway-car shock-absorbers, bumpers, rubber heels, and the like.

COMPRESSION MODULUS - The ratio of the compressive stress to the resulting compressive strain (the latter expressed as a fraction of the original height or thickness in the direction of the force). Compression modulus may be either static or dynamic.

COMPRESSION SET - The residual decrease in thickness of a test specimen measured 30 minutes after removal from a suitable loading device in which the specimen had been subjected for a definite time to compressive deformation under specified conditions of load application and temperature. Method A measures compression set of vulcanized rubber under constant load. Method B employs constant deflection. (See ASTM Method D-395.)

CONDENSATION - A chemical reaction in which two different molecules react to form a new compound of greater complexity, with the formation of water, alcohol, ammonia, etc., as a by-product.

CONDENSATION POLYMERIZATION - Polymerization of a monomer or monomers is by condensation, that is, with the splitting out of water, alcohol, ammonia, etc. Polyesterification is polymerization by condensation.

CONDUCTIVE - A rubber having qualities of conducting or transmitting heat or electricity. Generally applied to rubber products used to conduct static electricity. See CONDUCTIVITY.

CONDUCTIVITY (Electrical) - The ability of a substance to permit the passage of electric current. It is the reciprocal of the resistivity and is defined as the conductance, expressed in reciprocal ohms, or mhos, between 2 opposite faces of a unit cube of the material.

CONE PENETROMETER - An instrument for measuring viscosity of heavy materials. A cone of standard dimensions and weight is released on the surface of the material for a specified time interval and the depth of penetration is measured.

CONSISTENCY - The viscosity or solidness of a semi-solid or syrupy substance. It may be called the resistance to deformation. That property of a body by which it resists deformation or permanent change of shape. See VISCOSITY.

CONTACT CORROSION (CREVICE CORROSION) - Corrosion of a metal at an area where contact is made with a material usually non-metallic.

CONTAINER STABILITY - Period of time a compound will remain in satisfactory condition when stored in unopened containers. Synonymous with SHELF LIFE.

CONTINUOUS FILM - A coating film that is free of breaks, pinholes, or holidays.

CONTROL - A product of known characteristics which is included in a series of similar service, or bench, tests to provide a basis for evaluation of one or more unknown products.

CONVERTING - General term used in describing the manufacture of paper and plastic film products. Includes cutting, folding, gluing, and other operations.

COPOLYMER - A copolymer is a high polymer consisting of molecules containing large numbers of units of two or more chemically different types in irregular sequence. Butadiene and styrene form a copolymer known as GR-S.

COPPER CORROSION - When copper is coated with material and heated to 212° F. for 16 hours in a sealed tube, no blue-black color (characteristic of copper sulfide) should be apparent on the copper immediately adjacent to the tested material.

CORONA RESISTANCE - The ability of an elastomer acting as an insulator to withstand the effects of high voltage discharge. Indications of failure appear as surface cracks.

CORROSION - The deterioration of a metal by chemical or electrochemical reaction resulting from exposure to weathering, moisture, chemicals, or other agents or media. Also see ELECTROLYTIC CORROSION, GALVANIC CORROSION.

CORROSION FATIGUE - Reduction of fatigue durability by a corrosive environment.

COVERAGE - The area over which a given quantity of material can be applied at a specified thickness.

COVERING POWER - A term commonly used to describe the capacity of different pigments (usually white) to whiten or color a rubber compound. Synonymous with tinctorial power, tinting strength, and hiding power.

CRACKING - A fissured surface condition which develops on rubber articles exposed to the atmosphere, light, heat, or repeated bending or stretching. When the fissures are minute, the condition is called CRAZING. Also see ANTI-CRACKING AGENTS.

CRAZING - Fine cracks which may extend in a network on or under the surface of, or through a layer of, adhesive.

CREEP - The dimensional change with time of a material under load, following the initial instantaneous elastic deformation. Creep at room temperature is sometimes called COLD FLOW.

CRITICAL TEMPERATURE - A definite temperature above which a gas cannot be liquified by pressure. The term is loosely used sometimes to denote an approximate temperature below which a reaction such as vulcanization does not take place or proceeds only very slowly. Also used to denote a definite temperature below which an accelerator does not function properly.

CROCKING - Staining of a white cloth by rubbing lightly over a colored surface.

CROSS-LINKING - The union of two large molecules by means of an atom or a small molecule with two active portions. Sulfur is considered to cross-link rubber molecules during vulcanization, and 1, 4-divinylbenzene cross-links two long molecules of polystyrene.

CRUDE RUBBER - Natural rubber as it comes on the market is known as crude rubber.

CUMAR RESINS - Polymerized fractions of coal tar containing cumarone and indene hydrocarbons. They are neutral and melt from 50 to 65° C.

CURE - To change the properties of a material by chemical reaction, which may be condensation, polymerization, or vulcanization. Usually accomplished by the action of heat and catalysts, alone or in combination, with or without pressure. Also see OVER-CURE, SEMI-CURE, UNDERCURE.

CURE TIME - The time required to produce vulcanization at a given temperature. The cure time varies widely, being dependent on the type of compounding used, the thickness of the product, etc.

CURING TEMPERATURE - The temperature at which the rubber product is vulcanized.

CURING RANGE - In vulcanization, an approximate range of curing times at a given temperature, over which the physical properties of a vulcanizate do not change materially.

CUT BACK - A solvent dilution, generally applied to asphalt.

CYCLIC (Chemical) - A term used to describe chemical compounds whose structure consists of a ring of atoms as distinct from an open chain-like arrangement. Carbocyclic compounds have a ring of carbon atoms only (e.g., benzene). Heterocyclic compounds have, besides carbon, one or more elements other than carbon in the ring (e.g., pyridine).

CYCLIZED RUBBER - Isomeric natural rubber hydrocarbon formed by the action of sulfuric acid, sulfonic acids, sulfonyl chlorides, stannic chloride, mixtures of phenols and hydrochloric acid; and also by heat alone. They are tough and somewhat elastic, and hard and brittle. They have less unsaturation than the rubber hydrocarbon and therefore are cyclized.

D

DAMPING - (1) The progressive reduction of amplitude in free vibration. (2) The friction of any kind in a free vibration system causing the motion to decrease gradually to the vanishing point.

DANGEROUS CHEMICALS - Any substance or mechanical mixture or chemical compound of substances which is volatile or unstable or which tends to oxidize or decompose spontaneously, thus creating fire or explosion, or which may generate flammable or explosive gas, and which is capable of creating hazard to life, or property, when designated as such by rule or regulation of the Board of Fire Commissioners (Los Angeles, Calif.)

DEFORMATION - Any change of form or shape produced in a body by a stress or force.

DEGRADATION - Deterioration, usually in the sense of a physical or chemical process rather than a mechanical one.

DEGREE OF POLYMERIZATION - See POLYMERIZATION.

DEHYDRATION - Removal of water as such from a substance, or after formation from a hydrogen and hydroxyl group in a compound, by heat or dehydrating substance.

DEHYDROGENATION - Removal of hydrogen from a chemical compound usually by heat and generally in the presence of a catalyst such as nickel, copper, chromium oxide, sulfur, selenium, or platinum.

DELAMINATE - To split a laminated material along the plane of its layers. Sometimes used to describe cohesive failure of an adherend in bond strength testing.

DELAMINATION - Separation or splitting, usually as lack of adhesion in plied goods.

DENATURANT - A substance which renders alcohol unfit to use as a beverage.

DENSITY - The ratio of the mass of a body to its volume, or the mass per unit volume of the substance. When G.G.S. units are used, the density of a substance is numerically equal to the specific gravity of the substance referred to water at 4° C., the temperature of maximum density (1.0000) of water. For ordinary practical purposes, density and specific gravity may be regarded as equivalent.

DEPOLYMERIZATION - Separation of a more complex molecule into two or more simpler molecules chemically similar to and having the same empirical composition as the original. Reverse of POLYMERIZATION.

DETERIORATION - The undesired change in properties of a material caused by aging, weathering, or exposure to other agents and conditions.

DIELECTRIC - A non-conductor of electricity, an insulator.

DIELECTRIC CONSTANT - Specific inductive capacity. The dielectric constant of a material is the ratio of the capacitance of a condenser having that material as dielectric to the capacity of the same condenser having a vacuum as dielectric. The dielectric constant of a vacuum is unity; for all practical purposes, air at ordinary pressures has the same value and may be substituted for the vacuum.

DIELECTRIC STRENGTH - Breakdown potential. The potential per unit thickness of the dielectric required to cause puncture when the electrodes are in contact with the material and the voltage is increased at a specified rate.

DILUENT - A diluting agent. Any liquid or solid which, when added to another liquid or solid, reduces the quantity per unit volume of the base material in the total volume.

DIP COAT - A thin coat on a surface obtained by dipping the material to be coated into the coating material.

DISCOLORATION - Staining. Also changing or darkening in color from the standard or original.

DISPERSION - The act of causing colloidal particles of matter to separate and become uniformly scattered throughout a medium. Any system of matter in which finely divided colloidal particles of one or more phases (components) are uniformly scattered throughout another phase or medium; the components or phases may be solid, liquid, or gaseous (a wholly gaseous system is not considered a dispersion but a simple mixture). Colloidal solutions are examples of liquid dispersions; the dissolved or dispersed particles are not subdivided down to the molecular state as in true solutions. DEGREE OF DISPERSION - Fineness of subdivision of dispersed particles.

DISSIPATION FACTOR - Refers to the distortion in phase of the alternating voltage caused by the material. It is computed from the difference in phase angle from the imposed voltage. Low values are preferred.

DRYING OIL - See OIL, DRYING.

DRYING TIME - The time required for solvent dissipation after a film is spread. The drying process includes several stages. The first is known as "tacky" and starts almost immediately after application. The optimum point in the tacky stage is the earliest period when the adhesive may be touched lightly without transferring material to the finger. The bond should be made at this point. The second stage, "dust-free," is the time required for the film to reach the condition where if any dust settles on it, the dust will not become imbedded but may be wiped off after the material has been hardened.

The "tack-free" stage is the time required for the film to reach the condition where it can be touched with the finger without feeling the slight retention of surface stickiness. "Print-free" is closely related to this, although one stage later. It refers to the time required for the film to reach the condition where it may be touched with the finger without retaining the imprint of the finger on the surface of the film. The final stage, "hard-dry," is the time required for the film to become thoroughly hard so that it may be handled and polished if necessary.

DRY JOINTS - Lack of adhesion; more specifically, poor contact of adhering surfaces. See STARVED JOINT.

DRY SEAL ADHESIVE - One which is non-blocking except to itself. Two adherends may be precoated, dried, then bonded at any time using only normal pressure.

DUROMETER - An instrument for determining the hardness of rubber by measuring its resistance to the penetration (without puncturing) of a blunt indentor point impressed on the rubber surface against the action of a spring. A hand and a special scale indicate the resistance to penetration or "hardness." The scale reads from zero to 100, zero being very soft and 100 being very hard.

E

ELASTICITY - The property of matter by virtue of which it tends to return to its original shape after deformation such as stretching, compression, or torsion. It is the opposite of plasticity. It is often loosely employed to signify the "stretchiness" of rubber. As applied to rubber, it usually refers to the phenomenal distance to which vulcanized rubber can be stretched without losing its ability to return very nearly to its original shape; in this respect, rubber is the most elastic substance known. Also see COEFFICIENT OF ELASTICITY, MODULUS OF ELASTICITY, YOUNG'S MODULUS OF ELASTICITY.

ELASTIC LIMIT - The limiting extent to which a body may be deformed and yet return to its original shape after removal of the deforming force. Steel has a well-defined elastic limit (yield point) below which it is perfectly elastic; vulcanized rubber, on the other hand, shows no definite elastic limit, but takes more or less "set" depending on the amount of stretch given to it.

ELASTOMER - Elastomer is the name of a substance that can be stretched to at least twice its original length and, after having been stretched and the stress removed, returns to approximately its original length in a short time.

ELECTRICAL BREAKDOWN - The breakdown voltage of a material is the maximum potential gradient that the material can withstand without breakdown and passage of discharge. Also see BREAKDOWN TEST, BREAKDOWN VOLTAGE.

ELECTROLYTE - Any substance which, when dissolved in water or other suitable solvent, forms a solution that conducts electricity, the conductivity being due to ionic dissociation of the dissolved substance. Also, a solution of an electrolyte.

ELECTROLYTIC CLEANING - The process of degreasing or descaling a metal by making it an electrode in a suitable bath.

ELECTROLYTIC CORROSION - Measures the corrosion that would occur when pressure-sensitive materials under an electrical stress (voltage) are placed in contact with copper wires at an elevated relative humidity and temperature. As the humidity rises, this value increases rapidly. Higher values (1.0 is perfect) are preferred.

ELONGATION - Increase in length expressed numerically as a fraction or percentage of initial length.

EMULSION - A dispersion of fine particles or globules of a liquid in another liquid normally incompatible with it. "Tight" emulsions cannot be easily broken; "loose" emulsions can be easily broken to separate layers of relatively pure liquids. By custom, the term "emulsion" is generally misapplied to dispersions, as in the case of "asphalt emulsions."

ENDOTHERMIC - A chemical reaction which absorbs heat energy is said to be endothermic; a compound the formation of which absorbs heat is an endothermic compound. Such compounds are less stable than EXOTHERMIC compounds, many of them being explosive.

EROSION - Destruction of metal or other material by the abrasive action of liquid or gas. Usually accelerated by the presence of solid particles of matter in suspension and sometimes by corrosion.

EXOTHERMIC - A chemical reaction in which heat energy is liberated is termed exothermic; and a compound of which the formation involves the evolution of heat is called an exothermic compound. Exothermic compounds are more stable than ENDOTHERMIC compounds. Vulcanization of rubber with sulfur is an exothermic reaction.

EXTENDER - An ingredient, generally having some binding properties, added to a compound to reduce the proportion of primary binder needed.

EXTRUDER - A machine with a worm gear for extruding rubber through a die. Rods, strips, tubes, and rubber-covered wire are prepared by an extruder.

F

FILLER - Relatively non-adhesive substance added to an adhesive to improve its working properties, permanence, strength, or other qualities.

FILLET - A rounded bead or a concave junction of sealing compound over or at the edges of structural members.

FILM - Thin layer of material, not necessarily visible. "Free films" are not attached to any body. They are often called "unsupported films." "Supported films" have a flexible backing, usually cloth or paper, to give the film greater support and structural strength.

FLAME RESISTANT - Denotes a material which does not burn too readily, when source of flame is removed.

FLAME RETARDANTS - Substances mixed with rubber to retard its burning (i.e., highly chlorinated hydrocarbons). Neoprene is less flammable than natural rubber and GR-S.

FLAMMABLE - A volatile liquid or gas which has a flash point of 30° F. or lower. Flammable is synonymous with inflammable.

FLASH POINT - The temperature to which a liquid must be heated before its vapors will flash or burn momentarily when a small flame is applied. This ignition will not take place unless there is also a spark or open flame. There are several standard methods for determining flash point, most of which may be classified as "open cup" or "closed cup." See COC, TCC, TOC.

FLOW OUT - The ability of a material to level after application (whether brushed, sprayed, roll-coated or applied through pressure units). "Orange peel" is the surface appearance when a sprayed material does not flow or level. Excessive flowing on vertical surfaces is termed "sagging," usually caused by too much material or a solvent that is too slow drying.

FORD VISCOSITY - Viscosity as measured by a Ford Cup Viscometer. This viscometer is of the type which measures the flow of a liquid from an orifice under its own hydrostatic pressure. It measures kinematic viscosity. It draws its name from the Ford Motor Company, where it was first used.

FRICTION, COEFFICIENT OF - The ratio between the force pressing surfaces together and the force required to move one surface over the other.

G

GAGE (GAUGE) - The relative thickness of materials or articles that are made in different thicknesses. The thickness of fabric or rubber sheet, expressed in millimeters of thousandths of an inch. An instrument for measuring thickness or gage.

GALVANIC CELL - A cell made up of two dissimilar conductors in contact with an electrolyte or two similar conductors in contact with dissimilar electrolytes. More generally, a galvanic cell converts energy liberated by a spontaneous chemical reaction directly into electrical energy.

GALVANIC CORROSION - Corrosion associated with the current of a galvanic cell made up of dissimilar electrodes. Also known as couple action.

GARDNER-HOLDT VISCOSITY - The viscosity of any transparent liquid as measured by the Gardner-Bubble Viscosimeter. It is based on a standard series of water-white oils sealed in standardized tubes, each given a letter designation. By quickly inverting the tubes in the vertical position, the rates at which the air bubbles rise can be compared with a test sample.

GEL - A semi-solid, jelly-like condition of matter. A form of colloidal dispersion in which the dispersed component and the dispersing medium are associated to form a jelly-like mass. A solution of gelatin or glue in warm water is liquid and is termed a sol; on cooling, the liquid changes to a jelly termed a gel.

GELATION - Change from a liquid to a jelly-like state. In colloidal "solutions," the change from the sol to the gel condition.

GLUE - Originally, a hard gelatin obtained from hides, tendrons, cartilage, bones, and other connective tissues of animals. Also, an adhesive prepared from these substances by hydrolysis (application of water and heat), chemically known as collagen.

GR-A (NITRILE RUBBER) - Prepared by emulsion copolymerization of butadiene and acrylonitrile. Discovered and known in Germany as BUNA N and Perbunan, depending on the proportion of ingredients, 75/25 to 50/50. It shows greater resistance to the swelling action of solvents and oils, and has good abrasion resistance and good heat resistance. In the U.S.A., the nitrile rubbers are known as Butaprene N., Chemigum N, Hycar OR, and Paracril. See BUNA N, NITRILE RUBBER.

GR-S - See BUNA-S.

GROUT - The filler between courses of tile, especially ceramic tile.

GROUTING - Process of applying grout.

H

HARDENER - Substance or mixture added to an adhesive to promote or control the curing reaction. Also a substance added to control hardness of the cured film.

HARDNESS - Property or extent of being hard. Measured by extent of failure of the indentor point of any one of a number of standard hardness testing instruments to penetrate the product.

HEAT SEAL - To bond or weld a material to itself or to another material by the use of heat. This may be done with or without the use of adhesive, depending on the nature of the materials.

HETEROGENEOUS - Consisting of dissimilar elements, ingredients, components, or phases. The word may apply either to composition or structure; that is, a composition of matter may be heterogeneous as regards ingredients, but homogeneous in spatial distribution of these. In colloid parlance, the word is used frequently to describe the specific association of divers phases or compounds, that characterize colloid systems. The antonym of HOMOGENEOUS.

HIDING POWER - The power of a paint or pigment as used to obscure or render invisible a surface over which it is applied. It is one of the most important physical properties of a white pigment. It is determined by the difference in index of refraction between the material and its surrounding medium.

HOLIDAY - In coated fabrics, a place not covered by coating compound.

HOMOGENEITY - Uniformity of composition throughout the material.

HOMOGENEOUS - The opposite of HETEROGENEOUS. Consisting of the same element, ingredient, component, or phase throughout; or of uniform composition throughout. Crystalloids and crystalloid solutions (true solutions) are usually considered homogeneous systems of matter as opposed to colloids which are hetergeneous or polyphasic.

HYCAR - Trade name for several synthetic rubbers. Hycar OR is a nitrile rubber and is oil resistant. Hycar OS is a butadiene-styrene copolymer. Hycar PEA is a polyethyl acrylate synthetic rubber. (B. F. Goodrich Chemical Company)

HYDROCARBON - An organic compound containing only the elements carbon and hydrogen. Many thousands are known and for convenience are classified into groups of which the members possess similar properties and composition. Hydrocarbons may be gaseous (methane, ethylene, butadiene), liquid (pentane, benzene), or solid (rubber, naphthalene).

HYDROCARBON, RUBBER - The hydrocarbon of natural rubber, purified by solution and precipitation with alcohol. In pale crepe it is about 94% and in smoked sheet, 90-95%. Since isoprene is obtained from it by pyrolysin, its formula is generally written $(C_5H_8)X$. Its molecular weight varies but may be as high as over 1,000,000.

HYDROMETER - A device for determining the approximate specific gravity of a liquid by measuring the extent of immersion when the instrument floats in the liquid.

HYDROPHILIC - Having a fondness or attraction for water; said of colloids such as glue, gelatin, agar, starch gum arabic, etc., which are capable of swelling with water to form reversible gels.

HYDROPHOBIC - Having no attraction for water. The opposite of hydrophilic. Said of colloids such as rosin, or rubber, which do not form gels with water.

HYGROSCOPIC - Having the property of attracting moisture.

I

IGNITION POINT - This is the temperature at which the liquid gives off sufficient vapors to burn continuously upon the application of a flame, this temperature ordinarily being 40° to 80° higher than the flash point of the liquid. Most fire departments arbitrarily designate solvents as "extremely flammable," "flammable," and "combustible." These refer to solvents with flash points below 20° F., between 20° F., and 80° F. to 150° F. respectively. Those liquids with no flash points are termed "non-flammable."

IMMERSION - Placing an article into a fluid - generally so it is completely covered.

IMPACT - The single instantaneous stroke or contact of a moving body with another either moving or at rest, such as a large lump of material dropping on a conveyor belt.

IMPACT STRENGTH - Measure of toughness of a material, as the energy required to break a specimen in one blow.

IMPREGNATION - To fill the interstices of an article with a rubber compound. Generally applies to treatment of textile fabrics, yarns, and cords.

INFRARED - Infrared radiation is used for the spectroscopic examination of high polymers. Infrared absorption spectra of high polymers are usually obtained for wave numbers 1800 to 600 cm^{-1} and the percent of absorption recorded on a chart. Comparisons for structure are made of low molecular weight substances which contain what are assumed to be similar groups.

INSULATION RESISTANCE - The hindrance offered by an insulation to an impressed direct voltage determined by measuring the small leakage current which flows through the insulation.

INTEGRAL FUEL AND OIL TANKS - Those areas in an aircraft wing enclosed by fuel tight structural members - front and rear spars, upper and lower surfaces, web type bulkheads.

INTERFACE - The common boundary surface between two substances. Sometimes described as two surfaces with no space between them (for example, where the air contacts this paper is the air-paper interface).

INTERNAL MIXER - An enclosed mixing machine for rubber or or other suitable material, inside of which are two heavy mixing rotors which revolve in opposite directions with small clearance between themselves and the enclosing walls. The mixing chamber is jacketed or otherwise arranged for water-cooling, and is provided with a feeding hopper which can be closed by means of a pneumatically operated, vertical ram. Examples are the Banbury Mixer and the Shaw Intermix.

INTRINSIC VISCOSITY - The ratio of the difference between the viscosity of the solution at the given concentration and the viscosity of the pure solvent to the product of the viscosity of the pure solvent and the volume concentration of the solution. Volume concentration is expressed as:

$$\frac{\text{cc. (solute)}}{\text{100 cc. (solution)}}$$

Intrinsic viscosity is computed on the benzene soluble portion of the elastomer and is numerically equal to:

$$\frac{2.303 \times \log_{10} \times \text{relative viscosity}}{\text{grams of elastomer per 100 ml. of benzene}}$$

J

JOINT - The location at which two adherends are held together by an adhesive. Also see LAP JOINT, STARVED JOINT.

K

KETONES - Compounds containing the carbonyl group to which is attached two alkyl or aryl groups. Ketones, such as methyl ethyl ketone, are commonly used as solvent for resins and plastics.

L

LAP - A part that extends over itself or like part, usually by a desired and predetermined amount.

LAP JOINT - A joint made by overlapping adjacent edge areas of two adherends to provide facing surfaces which can be joined with an adhesive.

LAP SEAM - A seam made by placing the edge of one piece of material extending flat over the edge of the second piece of material.

LATEX - A milky juice, other than sap, secreted by certain plants in special cells usually present in all parts of the plant. Rubber latices from different plants vary widely in properties. Hevea latex, of greatest interest, is thin and white like milk and consists of a dispersion of rubber in an aqueous serum containing other substances.

LIFTING - Softening and penetration of a film by the solvents of another film resulting in raising and wrinkling.

LINER - Fabric used for rolling up lengths of sheeted, uncured rubber or uncured rubberized fabric to prevent the tacky rubber from sticking to itself. A piece of fabric placed between tacky rubber sheets of any kind to keep them separate. TREATED LINER - Fabric coated or impregnated with a glazing material of nitro-cellulose, viscose, or other composition to prevent tacky rubber from adhering to it.

LITER - A measure of capacity in the metric system equal to 61.022 cubic inches, 0.908 U.S. quarts dry and 1.0567 U.S. quarts wet.

LOSS FACTOR - The product of the dielectric constant (SIC) and power factor; a property determined for insulation.

LOW TEMPERATURE FLEXIBILITY - The ability of a rubber product to be flexed, bent, or bowed at low temperatures.

LUMPS - Surface protrusions, usually of the basic material as distinguished from foreign material.

M

M.A.C. ppm - This denotes for healthful conditions the maximum allowable concentration, parts per million, of the solvents in the atmosphere where workers will be exposed to them. In some cases the value given is quite arbitrary since the effects of some of the solvents upon the human body owing to inhalation are difficult to measure. Also some of the solvents now used are relatively new and their effects have not yet been definitely established.

MACMICHAEL VISCOSIMETER - An instrument for measuring the viscosity of fluids. It consists of a one-cm. diameter cylindrical spindle which is immersed in the specimen fluid to a depth of 4 cm. The spindle is suspended from wires of different diameters (expressed in B & I gage numbers) in such a manner that any torsion in the wire is indicated on a dial. The specimen in a half pint can is rotated on a turntable at 20 rpm, and the viscosity is read on the dial.

MASTIC - An adhesive of such a consistency that it must be applied by notched trowel, gob, or buttering methods.

MATRIX - A mold or form in which anything is cast or shaped. A continuous medium in which discrete particles are embedded as in mineral ores. In rubber compounds the rubber, being the continuous or outside phase in which compounding ingredients are dispersed, is sometimes called the matrix.

MELTING POINT - The temperature at which a polymer loses its crystalline character as evidenced by X-ray diffraction studies. Called also the "X-ray melting point." For low molecular weight solids, it is the temperature at which a solid melts and becomes liquid.

MERCAPTAN - An organic compound containing the -SH group, with either an aliphatic or an aromatic radical attached. Also known as a thiol. Dodecyl mercaptan is used as a modifying agent in the synthesis of rubberlike polymers.

METHANOL - Methyl alcohol, CH_3OH.

METHYL ETHYL KETONE - Known also as MEK. A useful low-boiling solvent possessing all the valuable properties of acetone without its extremely high volatility. It is a good solvent for nitrile rubber and for some of the more difficult soluble materials like the vinyl resins. Boiling point 80° C. (176° F.); flash point 19° F.; vapor pressure 77 mm/20° C.

METHYL ISOBUTYL KETONE - Known also as hexone. Boiling point 118° C.(244° F.); flash point 74° F.; vapor pressure 13 mm/20° C.

METHYL METHACRYLATE RESINS - A class of transparent resins produced by polymerizing methyl methacrylate. Used widely during World War II as a material for gun turrets and cockpit covers.

MIGRATION - The transfer of an ingredient in a rubber compound from one layer to an adjacent layer or to the surface.

MIL - One-thousandth of an inch.

MILLILITER - One-thousandth of a liter, equal to one cubic centimeter.

MISCIBLE - Soluble or compatible with each other, i.e., capable of being mixed to form a homogeneous mass.

MIXER - A machine, other than a MILL, for mixing rubber compounds, doughs, or cements. Mixers usually consist of a covered chamber or trough in which two blades or rotors revolve in opposition to each other. The axes of the blades may be horizontal as in the Banbury mixer (see INTERNAL MIXER) or vertical as in some types of cement mixers. In the latter case, the mixing chamber may rotate as well as the blades.

MIXING - The process of incorporating the ingredients of a rubber compound into the rubber, usually done on a mixing mill or in an internal mixer. The mising process consists in (1) breaking down the rubber, (2) gradual incorporation of compounding ingredients, (3) final working of the rubber ("cutting back") after all ingredients are in, and (4) removing the mixed compound from the mill in sheets. "Mixing," or simply "mix," also denotes the completed mixture.

MODULUS - In the physical testing of rubber, the ratio of stress to strain, i.e., the load in lb. per sq. inch or kilos. per sq. cm. of initial cross-sectional area necessary to produce a stated percentage-elongation. It is a measure of stiffness, is influenced by pigmentation, state of cure, quality of rubber, and other factors.

MODULUS OF ELASTICITY - Also known as Young's modulus (1807). It is the length of a column multiplied by the weight of the material per unit volume; or, the ratio of stress to strain within the elastic range.

MOISTURE - For all practical purposes, moisture may be considered as very finely divided particles of water. Moisture in the form of steam or of a jet of water is sometimes used in a kiln to regulate the humidity.

MOISTURE ABSORPTION - The absorption of moisture by a rubber or textile product.

MOLD - A form of matrix for shaping anything in a fluid or plastic condition. In rubber manufacturing, the forms in which rubber articles are vulcanized and given the shape desired.

MOTTLING - A film defect associated with spraying. It appears as a uniform series of approximately circular shape imperfections.

N

NECKING DOWN - The diminution of the cross-sectional area of a rubber product.

NERVE - Usually applied to unvulcanized rubbers or compounds. Refers to degree of toughness or resistance to deformation.

NITRILE RUBBER - A generic term comprising the various copolymers of butadiene and acrylonitrile. The copolymers vary essentially in butadiene-acrylonitrile ratios, Mooney values, and staining properties. They are resistant to solvents, oils, and greases, and to heat and abrasion. Trade names are Butaprene N, Chemigum N, Hycar OR, and Paracril. The Germans first produced the nitrile rubbers. See BUNA N.

NON-BLOCKING - Pertaining to an applied adhesive or coating film that will not adhere to itself and/or other surfaces under normal stacked storage conditions.

NON-POLAR SOLVENT - The aromatic or petroleum hydrocarbon group characterized by low dielectric constants (relatively nonconductive to electrical current).

NYLON - A condensation product of hexamethylene diamine and adipic acid. (E. I. duPont de Nemours & Co., Inc.)

O

OIL (DRYING) - Those oils that dry to a varnish-like film on exposure to air and sunlight. Linseed oil, chinawood oil, and perilla oil are the three principal vegetable oils of the drying class used in paint and varnish manufacture.

OIL PAINTS - The simplest form of paint consisting of drying oil, thinner, and drier only. (No resin is present.)

OPAQUE - Impervious to light, not transparent. That is, neither light nor an image can be seen through it.

OPEN TIME - Time interval between spreading the adhesive and completing the bond.

OPTIMUM CURE - State of vulcanization at which maximum desired property is attained.

ORANGE PEEL - A surface defect caused by vortex currents set up during evaporation of solvents of lacquers.

ORGANISOL - A dispersion of extremely finely divided resin particles suspended in a mixture of organic liquids which is incapable of dissolving the resin at normal temperatures.

ORGANOSOL - A colloidal solution or sol in which the dispersion medium or "solvent" is an organic liquid.

OSMOSIS - The tendency of water or crystalloids in aqueous solution to pass through colloidal septa such as animal membranes, vegetable parchment, gelatinous matter, etc. Colloids in solution (dispersion) show the property only to a slight extent (see dialysis). The pressure developed on the solution side of a semipermeable membrane is known as osmotic pressure.

OVERCURE - A state of excessive vulcanization resulting from overstepping the optimum cure, i.e., vulcanizing longer than necessary to attain full development of physical strength. Manifested by softness or brittleness, and impaired age-resisting quality of the vulcanizate.

OXIDATION - The formation of an oxide or more generally any increase in valence of an element. The act or process which oxidizes, combines, or increases the proportion of oxygen. The degradation of polymeric materials as a result of natural aging, severe working in air or accelerated aging in high concentrations of oxygen or ozone.

OZONE - An allotropic form of oxygen (O_3) produced by the action of electrical discharges on oxygen. It is a gas with a characteristic odor, and is a powerful oxidizing agent. Rubber compounds in a stretched condition are susceptible to the deteriorating action of ozone in the atmosphere, which results in a cracked condition.

OZONE RESISTANT - Withstands the deteriorating effects of ozone (generally cracking).

P

PAINT - A pigmented liquid composition which is converted to an opaque solid film after application in a thin layer. An oil base paint contains drying oil or oil varnish as the basic vehicle. A water paint contains a water emulsion or dispersion as the vehicle. This term is loosely used, sometimes designating the whole coating field.

PASS - Term used in spraying to refer to the movement of a spray gun in one direction. A double pass, back and forth, is actually a single coat.

PARLON - Trade name for a chlorinated natural rubber. (Hercules Powder Company)

PEELBACK - A method of separating a bond of two flexible materials or a flexible and a rigid material, whereby the flexible material is pulled from the mating surface at a 90° or 180° angle to the plane in which it is adhered. The stress is concentrated only along the line of immediate separation. Strengths are expressed in pounds per inch width (piw).

PEELING - The loosening of a rubber coating or layer from a base material, such as cloth or metal, or from another layer of rubber.

PENETROMETER - An instrument for determining the hardness (consistency) of plastic or elastic solids such as asphalt, bitumen, tar, rubber, etc. by the penetration of a standard weighted needle impressed on the surface of the sample under standard conditions of time, temperature, and load. Also see CONE PENETROMETER.

PERMANENT SET - The amount by which an elastic material fails to return to its original form after a deformation. In the case of elongation, the difference between the length after retraction and the original length, expressed as a percentage of the original length, is called the permanent set. Permanent set is dependent on quality and type of rubber, degree and type of filler loading, state of vulcanization, and amount of deformation. Also see ADHESIVE, SETTING.

PERMEABILITY - The quality or condition of allowing passage of liquids or gases through a rubber layer.

PETROLEUM - A mixture of hydrocarbons in a soft semi-solid form.

PETROLEUM ETHER - Low boiling aliphatic fractions derived from crude petroleum by fractional distillation. The low boiling ranges (near 100° F) and high evaporation rates restrict the use of such solvents in product manufacture, except where the very fast drying characteristic is preferred. Petroleum ethers bear no resemblance chemically to pure ethers. The only resemblance is the high evaporation rate.

PHENOLIC RESINS - Thermosetting resinous products obtained by a condensation reaction of phenol with formaldehyde or other aldehyde. They are sometimes compounded with nitrile rubbers.

pH (HYDROGEN ION CONCENTRATION) - The negative logarithm (to the base 10) of the hydrogen ion concentration of a solution.

$$\mathrm{pH} = \log \frac{1}{(\mathrm{H}+)}$$

PICKLE - A solution or process used to loosen or remove corrosion products such as scale and tarnish from a metal.

PIGMENT - Properly, a dry colored powder used for coloring paint, rubber, or other medium by direct admixture. In biology, any organic coloring matter whose presence in plant or animal tissues gives color to them. In rubber, the term is sometimes used to denote fillers and reinforcing agents.

PINHOLING - A film defect characterized by the presence of tiny holes. The term is rather generally applied to holes caused by solvent bubbling, moisture, other volatile products, dry spraying, or the presence of extraneous particles in the applied film.

PITCH - A black or dark heavy liquid or solid substance left as a residue after distilling tar, oil, and similar materials; also found naturally as asphalt. Pitches are named according to the source from which they are obtained as "bone pitch" from bone oil, "petroleum pitch" from petroleum, etc.

PIW - Pounds per inch width.

PLASTIC FLOW - When subjected to a stress, the internal units of a substance with such tendencies move and flow one over the other. A finite force is required to start the flow.

PLASTICITY - The property possessed by certain solid materials of keeping the shape or form imparted to them by a deforming force. It is characterized by a complete lack of plasticity and may be regarded as a state of matter in which internal friction and tendency to flow balance each other. Plasticity is produced in many rigid materials by heating them, and enables such materials to be shaped in molds under pressure to any desired form. The plasticity of rubber which has been worked on a mill is more or less imperfect; but it is the ability of rubber to assume this plastic state under the influence of mechanical work and heat, and oxygen, that enables it to be worked through the various processes of manufacture.

PLASTICIZER - A substance that softens or plasticizes another substance through its solvent action.

PLASTICS - Natural and artifically prepared organic polymers of low extensibility as compared with rubber, which can be molded extruded, cut, and worked into a great variety of objects, rigid or non-rigid, and used as substitutes for wood, metals, glass, rubber, leather, fibers, and textile materials. Many are also referred to as synthetic resins. The first commercial plastic was celluloid, introduced by Hyatt in 1869; and the first commercial thermosetting resin was introduced by Baekeland in 1909. There are two general methods of formation -- condensation polymerization, as in the case of phenol-aldehyde resins, and vinyl polymerization, as in the case of polyvinyl chloride resins. Certain plastics are derived from casein. Some of the more recent products are organo-inorganic, such as the silicones.

PLASTISOL - A colloidal dispersion of a resin in a plasticizer.

PLASTOMETER - An instrument for measuring the plasticity of uncured rubber. One type is based on rate of extrusion of the rubber through an orifice under controlled pressure and temperature. Another type is based on compression of a definite volume of the rubber between paralled plates, under controlled pressure and temperature, measures final thickness and recovery, and is exemplified by the Williams and Goodrich instruments. A third type, now the most widely used, and represented by the Mooney Plastomer, measures the shearing action of a definite volume of the rubber between two parellel, rotating metal discs at a controlled temperature. The Pusey-Jones Plastometer does not measure plasticity of uncured stocks, but hardness of vulcanizates.

PLEXIGLAS - A proprietary term applied to resinous acrylic derivations.

POISE - The c.g.s. unit of viscosity. The term poise is derived from the name of the man who discovered the laws of flow-Poiseuille.

POLAR - In an unsymmetrical molecule such as that of water, or sulfur dioxide, the mean center of all the electronic charges does not coincide with the mean electrical center of the nuclei. Such a molecule is termed polar; it may be regarded as an electric doublet or dipole, analogous to a tiny magnet. Polar molecules have an electric moment which is equal to the distance between the two electrical centers multiplied by the total electric charge of either sign in the molecule. Liquid polar molecules in an electric field tend to orient themselves so that their potential energy is reduced to a minimum. When the elctrical centers of a molecule coincide, the molecule has no electric moment and is said to be non-polar.

POLAR SOLVENTS - Such solvents as alcohols and ketones that contain hydroxyl or carbonyl groups have high dielectric constants and show strong polarity.

POLYAMIDE RESINS - A class of resins usually derived from adipic acid and alkylene diamines. Nylon is a well-known polyamide resin.

POLYBUTADIENE - Various elastomeric polymers of 1, 3-butadiene. They can be prepared by treatment of butadiene with metallic sodium, by emulsion type of polymerization, and by Alfin catalytic polymerization.

POLYISOPRENE - Elastomeric polymers of isoprene were the very first synthetic rubbers prepared by G. Bouchardat in 1879 and 1884 by William Tilden, who also in 1886 noted the spontaneous polymerization of isoprene probably by the action of peroxides formed by oxygen in the air. In 1910 Matthews and Strange in England and Harries in Germany polymerized it with metallic sodium. Isoprene is also polymerized by emulsion recipes and by the Alfin catalyst. Polyisoprene adds hydrogen chloride to form the hydrochloride, whereas polybutadiene does not.

POLYMER - A very long chain of units of monomers prepared by means of an addition and/or a condensation polymerization. The units may be the same or different. There are copolymers, dipolymers, tri- or ter-polymers, quadripolymers, high polymers.

POLYMERIZATION - Chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. Degree of polymerization - The number of base units per molecule, if the molecules are composed of regularly repeating units; or the number of monomeric units per molecule, if the molecules have been produced by polymerization from identical monomers. See CHAIN THEORY OF POLYMERIZATION.

POLYSULFIDE ELASTOMER - A synthetic rubber-like elastomer practically insoluble in oils and solvents, prepared from ethylene chloride and sodium tetrasulfide, commonly called Thiokol. It was the first commercial synthetic elastomer (U.S.A. 1930). Other dichlorides used are di-(2-chloroethyl) ether and di-(2-chloroethyl) formal. These are not vulcanized with sulfur but by heating with zinc oxide. Also see THIOKOL, RUBBER, SYNTHETIC RUBBER.

POROSITY - Presence of numerous minute voids in the cured material. Also, may refer to open cells in the skin of cellular rubber and in this case is not a defect.

POT LIFE - The rating in hours of the time interval following the addition of accelerator before a chemically curing material will become too viscous to pass predetermined viscosity (consistency) requirements. Closely related to WORKING LIFE.

PRESSURE SENSITIVE ADHESIVE - Type of adhesive that retains its tack even after complete release of the solvent.

PRIMER - Special coating designed to provide adequate adhesion of a coating system to new surfaces. In the case of new wood, it is used to allow for the exceptional absorption of the medium. Metal priming coatings for steel work contain special anti-corrosive pgments or inhibitors, such as red lead, white lead, zinc powder, zinc chromate, etc.

PSI - Pounds per square inch.

PYROMETERS - Mold, needle, roll, wall type. Instruments for measuring temperatures, especially beyond the range of mercurial therometers. They use the change of electrical resistance, the production of a thermo-electric current, the expansion of gasses, the specific heat of solids, or the intensity of the heat or light radiated.

R

REINFORCEMENT - Stiffening effect of solids (e.g., carbon black) on unvulcanized elastomer mixture, and enhancement by solids of properties of vulcanized mixture (e.g., increased modulus, tensile strength, toughness, resistance to abrasion and tear).

RESILIENCE - (1) In metals and some other materials, resilience is the amount of energy stored up in a deformed body, and as no loss of energy is contemplated, it is also the amount of energy recoverable when the force producing the deformation is removed. (2) In rubber or rubber-like materials subjected and relieved of stress, resilience is the ratio of energy given up on recovery from deformation to the energy required to produce the deformation. Resilience for rubber is usually expressed in percent.

RESIN - Any of a class of solid or semi-solid organic products of natural or synthetic origin, generally water-insoluble and having little or no tendency to crystallize, although some are readily dispersible in water and a few are readily crystallized. Also see CUMAR RESIN, PHENOLIC RESINS.

RESINS, A, B, & C STAGES - A-Stage: Thermosetting resins in early stage of reaction when they are soluble and fusible. B-Stage: Thermosetting resins at intermediate stage of reaction where they soften when heated and swell in contact with liquids but do not entirely fuse or dissolve; preferred stage for the resin and molding compositions. C-Stage: Thermosetting resins in final stage of reactions where they are infusible and insoluble; state of the resin in the final molded article.

RETARDER - Any substance whose presence in relatively small proportion retards a chemical reaction. Specifically a substance which, when added in small proportion to a rubber compound, retards the rate of vulcanization. An anti-scorching agent (e.g., phthalic anhydride, salicylic acid).

REVERSION - (1) The change which occurs in vulcanized rubber as the result of aging or overcuring in the presence of air or oxygen, usually resulting in a semi-plastic mass. (2) It is the basis of rubber reclaiming processes and is aided by the use of swelling solvents, chemical plasticizers, and mechanical disintegration to obtain a workable mass.

REX HARDNESS - The hardness of a "soft" vulcanized rubber or other similar elastic material as measured by the Rex Hardness Gage.

RHEOLOGY - Science of deformation and flow of matter. Deals with laws of plasticity, elasticity, viscosity and their connection with paints, plastics, rubber, oils, glass, cement, etc.

RIGIDITY - The property of bodies by which they can resist an instantaneous change of shape. The reciprocal of ELASTICITY.

RPM - Abbreviation for revolutions per minute.

RUBBER - The name universally used to designate the more elastic substances which constitute the chief raw materials of the rubber industry. They may be of vegetable origin or synthetic. The natural products are obtained exclusively from latex-bearing, tropical trees belonging to several botanical orders, growing wild or cultivated on plantations, and from certain shrubs. Synthetic or artificial rubbers are made by the artificial polymerization of certain unsaturated hydrocarbons (straight or chlorinated) or by the copolymerization of mixtures of unsaturated hydrocarbons, or of mixtures of unsaturated hydrocarbons with other polymerizable substances such as acrylonitrile. This definition is somewhat rigorous and hence excludes certain materials such as Thiokol, polyacrylates, and silicones which are frequently referred to as rubbers, but which are more properly classified as elastomers -- a broader classification. Examples of synthetic rubbers as defined are GR-5, GR-1 (butyl rubber), neoprene, and nitrile rubbers. Also see BUNA N, BUNA S, BUTADIENE, BUTYL RUBBER, CAOUTCHOUC, CHLORINATED RUBBER, COLD RUBBER, CRUDE RUBBER, CYCLIZED RUBBER, GR-A, GR-S, HYDROCARBON (RUBBER), NITRILE RUBBER, SILICONE RUBBER, SYNTHETIC RUBBER.

S

SAGGING - Running or flowing in the finish of a coating caused by the application of too much material and/or by material that is too thin.

SALT SPRAY TEST - A testing method to compare the corrosion resistance of materials, usually coatings. One of the best corrosion test media known is vapor of salt solutions. The most common procedure is to spray a fine mist of a 20% by weight solution of sodium chloride (iron free) in water into a large closed container in which the test panels are suspended. The operating temperature is about 96° F.

SCORING - A variety of wear in which the working face acquires grooves, axial or circumferential, according to whether the motion is reciprocating or rotary. Also, applied to a similar effect on the rigid member.

SEALANT - A material used to fill a joint, usually for the purpose of weatherproofing or waterproofing.

SEALER - (1) A continuous film to prevent the passage of liquids or gaseous media; a high-bodied adhesive generally of low cohesive strength to fill voids of various sizes to prevent passage of liquid or gaseous media. (2) A coating used to seal the sand-scratched surface of a primer in order to obtain a smooth uniform paint base over rough metal. Sealers are products of low pigmentation.

SEAM- A line formed by joining material to form a single ply or layer. Also see LAP SEAM, TRANSVERSE SEAM.

SEMI-CURE - Partially cured. A term frequently used to designate the first cure of an article that is given more than one cure in its manufacture.

SET - A term used rather loosely to describe the point at which a film has either dried sufficiently (released enough solvent) so that it is tough or hard, or has cured sufficiently after the addition of the accelerator to sustain the required load or pressure. Also see PERMANENT SET.

SHEAR - The progressive relative displacement of adjacent layers because of strain, or a lateral motion.

SHEAR TEST - A method of separating two materials by forcing (either by compression or tension) the interfaces to slide over each other. The force exerted is distributed over the entire bonded area at the same time. Strengths are recorded in psi (pounds per square inch).

SHELF AGING - A method of determining the resistance of rubber articles to perishing by storing them under atmospheric conditions, either in light or in darkness, and testing them after definite lapses of time. The natural deterioration of rubber articles kept in storage or "on the shelf" under atmospheric conditions.

SHELF LIFE - The period of time a packaged adhesive, coating, or sealer can be stored under specified temperature conditions and remain suitable for use.

SHORE HARDNESS - A value of specific degree of hardness as obtained from the Shore Hardness tester (durometer), a small pocket-type instrument which gives a measure of the resistance of a rubber surface to penetration of a blunt point pressed onto the surface by hand. The accuracy decreases in the softer range of rubbers. (ASTM:D-314)

SHRINKAGE - The percent loss of weight of a material when put through a particular process as, for example, the washing and drying of crude rubber. The percent diminution in area or volume of a piece of processed unvulcanized rubber compound on cooling. Also, the contraction of molded vulcanized rubber on cooling.

SILICA GEL - A form of colloidal silica which has the appearance of coarse sand and has many fine pores. It is extremely absorbent and is used as a catalytic material.

SILICONE RUBBER - A rubber prepared by the action of moisture on dichloro-dimethyl-silicon.
These rubbers withstand temperatures from -120 to 500° F. They are vulcanized with benzoyl peroxide.

SIZING - Material, or process of applying material, used to fill pores on a surface and thus reduce absorption of a subsequently applied adhesive or otherwise modify properties of the adherend to improve adhesion.

SOFTENING POINT - The temperature at which a prescribed load will cause the failure of a one-square inch shear bond of cloth to steel. Since softening under heat is progressive, increasing with temperature, it is rarely stated that a product is hard or soft at a certain temperature. The preferred method is to report what weight per inch area it can support without failure. A bond under high tension, for instance, will not withstand as much heat as one under light tension, and raising or lowering the temperature will to a point decrease or increase the apparent strength of an adhesive.

SOLIDS (PLASTIC AND ELASTIC) - Solid: A substance which undergoes permanent deformation only when subjected to shearing stress in excess of some finite value characteristic of the substance (yield stress). Plastic Solid: A substance which does not deform under a shearing stress until the stress attains the yield stress, when the solid deforms permanently. Elastic Solid: A substance in which, for all values of the shearing stress below the rupture stress (shear strength), the strain is fully determined by the stress regardless of whether the stress is increasing or decreasing.

SOLUBILITY - The degree to which a substance will dissolve in a particular solvent usually expressed as grams dissolved in 100 g. of solvent.

SOLUTION - A homogeneous mixture of two or more components in a single phase. The proportion of the components may be varied within certain limits.

SOLVENT - The medium within which a substance is dissolved. The term is most commonly applied to liquids used to bring particular solids into solution (e.g., dichloroethylene is a solvent for rubber).

SOLVENT SWELL - Nearly all rubber products swell in solvents, some of them finally dissolving in them. The swelling of a product in different solvents or the swelling of different rubbers in the same solvent can be compared by measuring the sizes of the swelled specimens and tabulating the results.

SPECIFIC GRAVITY - $$\text{Specific gravity} = \frac{\text{weight of substance}}{\text{weight of equal volume of standard}}$$

It is the ratio of the weight of any volume of a substance to the weight of an equal volume of a standard substance at stated temperatures. For solids or liquids the standard substance is usually water, and for gases the standard is air or hydrogen.

SPECIFIC VOLUME - This is the reciprocal of specific gravity (1 divided by specific gravity), and represents the volume in liters of 1 kg. or the volume in cubic feet of 1,000 lb. (998.9 exactly). It also represents the ratio between the volume of 1 lb. of water (27.72 cu. in.) and the volume of 1 lb. of the material in question.

STABILITY - That property which allows a compound to be stored under specified conditions without loss of its original properties.

STARVED JOINT - A joint that has an insufficient amount of adhesive to produce a satisfactory bond. See DRY JOINTS.

STORMER VISCOSIMETER - An apparatus consisting of a vertically disposed cylinder which is caused to rotate at a uniform rate in latex for the determination of its viscosity.

STRENGTH - The maximum stress required to overcome the cohesion of a material. Quantitative: A complex property made up of tensile strength and shearing strength. The force required to break a bar of unit cross-section under tension, that is, the tensile strength. It depends not only upon the cohesion, but also the consistency and therefore at least to some extent upon the rate of application of the load. Strength involves the idea of resistance to rupture.

STRESS - Force per unit of original cross-sectional area required to stretch a specimen to a stated elongation. (ASTM: D-412).

STRESS-STRAIN - The relationship of load and deformation in any soft-vulcanized rubber compound or other body under a stress. Usually expressed in pounds per square inch or kilograms per square centimeter of initial cross-sectional area, required to stretch rubber to a given percent elongation. The stress-strain curve shows the relationship graphically from zero loading to rupture. (One kg. per sq. cm. = 14.22 lb. per sq. in.)

SURFACE PREPARATION - The procedure required with respect to a foundation surface or the materials to be adhered which will promote optimum performance of an adhesive, coating, or sealer. For example, if higher bond strength is required, abrading and/or acid etching the surface can be the means of improving the adhesion of the bonding material to the mating surfaces. Common methods of surface preparation are solvent washing, sandblasting, and vapor degreasing.

SURFACE TENSION - The contractive force in the surface film of a liquid which tends to make the liquid occupy the least possible volume. It is due to the tendency of the body of liquid to attract the unbalanced surface molecules toward the interior. It is expressed in dynes per centimeter and varies for different liquids, being very high for mercury and very low for ether; and it decreases with increasing temperature. Lyophilic colloids in sol form, such as soap and gelatin solutions, lower the surface tension of the medium appreciably, while lyophobic colloids have practically no effect.

SUSPENSION - A dispersion of material particles in a liquid medium. Suspensions may vary from coarse-grained mixtures, the particles of which are visible to the naked eye and settle out readily, to colloidal solutions or sols in which the suspended particles are so fine that they can only be seen with the ultramicroscope and show no tendency to settle. The latter are usually termed suspensoids.

SWELLING - The property of raw or vulcanized rubber of absorbing organic liquids such as benzene, gasoline, etc., and swelling to many times its original volume. The property is also shown by other colloids in contact with other liquids. In a general sense, it may be any increase in volume of a solid substance caused by the absorption of a liquid.

SYNTHETIC RUBBER - Elastomer manufactured by a chemical process as distinguished from natural rubber obtained from trees. Typical examples are GR-S, butyl, neoprene, nitrile, and Thiokol "rubbers."

T

TACK, DRY - Property of certain adhesives, particularly nonvulcanizing rubber adhesives, to adhere on contact to themselves at a stage in evaporation of volatile constituents, even though they seem dry to the touch.

TACKINESS - The stickiness of the film while in the stage of drying. For instance, after a paint or varnish sets up it usually retains a sticky or tacky feel for some time until it is practically dry. Stickinesss: A quality possessed by a solid having a low yield value and high mobility by means of which contact readily results in adhesion. For example, adhesive, varnish, printer's ink, and gold size under working conditions are tacky or sticky substances. When most of the above dry out, set, gel, or harden through chemical or other change, they lose tack or stickiness. Those compounds that retain tack long after drying are said to be "permanently tacky" or to possess "after tack."

TALC - Hydrous magnesium silicate, $Mg_3Si_4O_{11}.H_2O$; specific gravity = 2.6 to 2.9, hardness = 1; index of refraction = 1.57. It is soft mineral, with a soapy feel. In rubber it acts as a filler and shows no reinforcing property.

TCC - Tagliabue Closed Cup, the standard test instrument and method by which flash point values for pure and mixed solvents are obtained.

TEMPERATURE - The degree of heat or cold as measured in terms of degrees Centigrade or Fahrenheit.

TENSILE STRENGTH - The capacity of a material to resist a force tending to stretch it. Ordinarily the term is used to denote the force required to stretch a material to rupture, and is known variously as "breaking load," "breaking stress," or "ultimate tensile strength." In rubber testing, it is the load in pounds per square inch or kilos per square centimeter of original cross-sectional area, supported at the moment of rupture by a piece of rubber, on being elongated at a constant rate.

TENSION PULL - A term for the total pull in pounds shown at the conclusion of a tension test. This test subjects, for example, a hose assembly to increasing tension load in a suitable testing machine until failure occurs either by separation of the specimen from the end fittings or by rupture of the hose structure.

TENSION STRESS-STRAIN TESTING - Determination of stress and strain (tensile strength and elongation) with the use of dumbbell specimens in conformance with ASTM Method G - 412 at $23 \pm 1.1^\circ C$. ($73.4 \pm 2^\circ F$). Rings may also be used. Also see STRESS-STRAIN.

THERMAL CONTRACTION - Contraction caused by decrease in temperature.

THERMAL EXPANSION - Expansion caused by increase in temperature. It may be linear or volumetric.

THERMOPLASTIC - Capable of being repeatedly softened by heat and hardened by cooling.

THERMOSETTING - Having the property of undergoing a chemical reaction by the action of heat, catalysts, ultraviolet light, etc., leading to a relatively infusible state.

THIOKOL - A commonly used name for the first commercial synthetic elastomer, 1930, produced by the Thiokol Chemical Company. Thiokol A is produced by the reaction of ethylene dichloride and sodium tetrasulfide, $Cl\text{-}CH_2CH_2Cl + Na_2S_4 \rightarrow (-CH_2CH_2-S_4-)X$. The atoms of sulfur may all be in a straight line. Thiokol is vulcanized by heating with zinc oxide and is important because it is practically insoluble in petroleum oils. Thiokols are also prepared from the other dichloro compounds: di-(2-chloroethyl) ether, $Cl\text{-}CH_2CH_2OCH_2CH_2Cl$, and di-(2-chloroethyl)formal, $Cl\text{-}CH_2CH_2OCH_2OCH_2CH_2Cl$. The latter Thiokols are somewhat more soluble than Thiokol A. See POLYSULFIDE ELASTOMER, RUBBER, SYNTHETIC RUBBER.

THIXOTROPIC - A term used to describe certain colloidal dispersions which, when at rest, assume a gel-like condition but which, when agitated, stirred, or subjected to pressure or other mechanical action at ordinary temperatures, are transformed into a liquid condition. The action is reversible and can be repeated at will. Thixotropic colloids occur in nature, the best-known example being Bentonite, a colloidal American clay. Rubber dispersions are not thixotropic but can be made to exhibit this property by incorporating with them thixotropic colloids such as Bentonite.

TIE COAT - One layer of a coating system used to improve the adhesion of adjacent or succeeding coats.

TOC - Taliabue Open Cup, an instrument and test method for determining flash points of solvents and finished compounds (adhesives, coatings, sealers, etc.) Flash points by the open cup method ordinarily will be 10 to 30° F higher than those determined by the closed cup (TCC) method.

TOXICITY - A term referring the physiological effect of absorbing a poisonous substance into the system either through the skin, mucous membranes, or respiratory system. When describing their toxic effect, solvents are usually classified as having high, medium or low toxicity, depending upon whether a solvent vapor concentration of less than 100, 100 to 400, or over 400 parts per million respectively is the maximum amount permissible in the air for safe or healthful working conditions.

To enlarge upon this, a short guide to safe working conditions has been supplied by the U.S. Public Health Service for the Army Industrial Hygiene Laboratory. This reports that for practical laboratory and plant purposes "in general," the maximum allowable concentrations have been set variously from 50 to 200 parts per million for the very toxic aromatics (i.e., benzene, toluene and xylene) and halogenated hydrocarbons (such as carbon tetrachloride, trichlorethylene, ethylene dichloride and propylene dichloride). These solvents may be considered as definitely hazardous. They cannot be endured by the workmen for even a short time except at extremely small concentrations without the possibility of dangerous after effects or without affecting their ability to work.

An added danger with this group is that the effect is cumulative with prolonged and repeated exposure. While other solvent types can be easily eliminated through the lungs and digestive passages, this group tends to linger in the system to accumulate to the toxic level.

For the less toxic groups of alcohols, esters, ethers and ketones, such as ethyl alcohol, isopropanol, ethyl acetate, butyl acetate, acetone, methyl ethyl ketone and hexone, a maximum allowable concentration range of 200 to 400 parts per million permits safety. This solvent group is considered mildly hazardous. It can be endured by the workmen for a short time within maximum permissible concentrations without serious disturbances or dangerous after-affects.

According to the guide, "For the not particularly toxic paraffins and naphthas, such as gasoline, petroleum naphtha, Stoddard solvent, mineral spirits and VM&P naphthas, the maximum allowable concentration range was 500 to 1,000 parts per million." These are the solvents which can be considered harmless or which cause no injuries to the workman's health after long association with them in everyday plant routine.

TRANSLUCENT - Permitting the passage of light but diffusing it so that objects beyond cannot be clearly distinguished.

TRANSVERSE SEAM - A seam joining two materials across the width of the finished product.

U

ULTIMATE ELONGATION - The elongation at the moment of rupture.

ULTRAVIOLET LIGHT - A form of luminous energy occupying a position in the spectrum of sunlight beyond the violet, and having wavelengths of less than 3900 Angstrom units, which is the limit of the visible spectrum. Ultraviolet rays are very active chemically, exhibit bactericidal action, and cause many substances to fluoresce.

UNDERCURE - Degree of cure less than optimum. It may be evidenced by tackiness, loginess, or inferior physical properties.

V

VEHICLE - The liquid portion of a finishing material consisting of the binder and volatile thinners.

VISCOSIMETER OR VISCOMETER - An instrument used for measuring the viscosity or fluidity of liquids and plastic materials. Various types are in use, as the Baybolt, Redwood, Engler, based on rate of flow through a tube; some types, (Brookfield, Stormer) are based on the torsion principle, and others on the time taken for a metal ball to fall through a column of the liquid of definite time length. For rubbers, including GR-S, the Mooney viscometer is widely used for both the raw and compounded material.

VISCOSITY - A manifestation of internal friction; opposed to mobility. The property of fluids by which they resist an instantaneous change of shape (i.e., resistance to flow). It is measured by the force required to cause two parallel liquid surfaces of unit area and unit distance apart to slide past each other in the liquid with unit velocity; this is expressed in poises, or dyne-seconds per square centimeter. Water at 20.2° C has a viscosity of 1 centipoise and is taken as the standard of comparison. A number of terms have been proposed for special applications of viscosity. These are listed below:

Syrup: Material that slumps under its own weight (will not maintain its shape) when made into a ball with a diameter of one inch or less.

Thin: Any material tested on a Ford Cup or any material testing up to 40 on a #26 MacMichael wire.

Medium: Any material testing 40 to 300 on a #26 MacMichael wire and up to 40 on a #22 MacMichael wire.

Heavy: Any material testing 40 to 100 on a #22 MacMichael wire or from 0 to 65 on a #18 MacMichael wire.

Paste or Mush: Material that will flow or slump under its own weight (not hold its shape) in a diameter greater than one inch. Viscosity is recorded in the range of 400-150 cone penetrometer.

Dough: Material that will generally not flow under its own weight. Viscosity is recorded in the range of 150 to 0 cone penetrometer.

VOID - Non-filled area or hole.

VOLATILE - Property of liquids to pass away by evaporation.

VOLUME RESISTIVITY - The resistance between two electrodes which cover opposite faces of a cubic centimeter, provided the resistance of the surface layer is so high that it is not responsible for any appreciable part of the current.

W

WATER ABSORPTION - The process of assimilating or soaking up water.

WATER DISPERSION - A dispersion or suspension of finely-divided particles of any colloid or insoluble material in water. Used commercially for many dispersions such as reclaimed rubber, vulcanizing agents, and coloring pigments. Water dispersions of GR-S, neoprene, and nitrile rubbers are commonly referred to as latex.

WATER RESISTANCE - The ability to withstand swelling by water for a specified time and temperature, usually 48 hours at 100° C., expressed as percentage swelling or volume increase of specimen.

WEATHEROMETER - An apparatus for estimating the comparative resistance of soft vulcanized rubber compounds to deteriorating when exposed to light having a frequency range approximating that of sunlight but with a greater intensity in the ultraviolet range than sunlight. The criterion used in estimating resistance to light again is the percentage decrease in tensile strength and in elongation at break. A supplementary criterion is the observed extent of surface crazing and cracking. During the test, water sprays of clean water are forced on the specimens to simulate the action of rain. (ASTM: D-750)

WORKING LIFE - Period of time during which an adhesive, sealer, or coating, after mixing with catalyst, solvent, or other compounding ingredients, remains suitable for use.

Y

YIELD STRENGTH - The stress at which a material exhibits a specified limiting permanent set. Determined by a measurable value of plastic yielding of the material, above which the material is considered to be damaged and below which the damaging effects are considered to be negligible.

YOUNG'S MODULUS OF ELASTICITY - (1) In many non-rubber materials, Young's Modulus may be taken in tension or compression; the values are approximately the same. It is the ratio of stress to strain, expressed in psi per unit strain. (2) In rubber, the assumption that tension modulus equals compression modulus is valid only for extremely small deformations and for certain shapes such as specified in ASTM: D-797, "Standard Method of Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers," and ASTM: D-1053 (Sec. 7), "Measuring Low-Temperature Stiffening by the Gehman Torsional Apparatus."

The list of registrants on pages 225 to 244 includes all persons registered at the BRI 1962 Spring Conferences, including the conferences on:

Solar Effects on Building Design
New Joint Sealants: Criteria, Design, and Materials
New Building Research, Spring 1962

Registrants, BRI 1962 Spring Conferences

ABERTH, W. C.
Asst. Tech. Dir., DAP, Inc., 160 Dayton Ave., Xenia, Ohio

ACHENBACH, Paul R.
Chief, Mech. Systems Section, National Bureau of Standards, Washington 25, D.C.

ADERHOLD, George W.
Sup. Architect, Bureau of Prisons, Washington 25, D.C.

ALBERTALLI, Stephen L.
Prod. Supt., Corning Glass Works, Corning, N.Y.

ALBRIGHT, G.H.
Dir., Shelter Research & Assoc. Prof., Pa. State University, 133 Hammond Bldg., University Park, Pa.

ALLEN, G. F.
Dow Chemical Co., Midland, Mich.

ALM, Henry G.
Mgr., Bldg. Products Div., The Adams & Westlake Co., 1025 N. Michigan, Elkhart, Ind.

AMSTOCK, Joseph S.
ProductsResearch Co.,410 Jersey Ave., Gloucester City, N.J.

ANDERLE, Joseph A.
Dir. of Material & Standards Control, Levolor Lorentzen, Inc., 720 Monroe St., Hoboken, N.J.

ANDERSON, H.E.B.
Construction Editor, Plant Engineering, 308 E. James St., Barrington, Ill.

ANDERSON, James E.
Sales Promotion Engr., Architectural Stainless Sales Div., Crucible Steel Co., Four Gateway Center, Pittsburgh, 22, Pa.

ANDERSON, LeRoy O.
Engineer, U.S. Forest Products Laboratory, North Walnut St., Madison 4, Wis.

ANDERSSON, Olof
Nya Murbruksfabrikens (New Adhesives Factory), Jungfurgatan 8, Stockholm 5, Sweden

ANDREWS, Gordon E.
Procter & Gamble Co., Cincinnati, Ohio

ARNISON, Gordon H.
Mgr. Architectural Products, Laurential Blvd., Montreal, Quebec, Canada

ARNSTEIN, Sherry
Washington Editor, Current Magazine, National Press Bldg. #827, Washington, D.C.

BAKER, A. H.
ResearchConsultant, Pittsburgh Corning Corp., Port Allegany, Pa.

BAKER, Allen E.
Sales Mgr., Bldg. Industry Sales, Products Research Co., 2919 Empire Ave., Burbank, Calif.

BAKER, Irvin
Tech. Dir., The Farboil Co., 801 Key Highway, Baltimore 30, Md.

BALCOMB, Philip E.
Mgr., Construction Sales, Presstite Div., Martin Marietta Corp., 3738 Chouteau St. Louis 10, Mo.

BALL, Fred M.
Chief Chemist, Eastman Chemical Products, Inc., Kingsport, Tenn.

BARNES, Tracy W.
Mgr. of General Engineering, The Pillsbury Co., 608 2nd Ave. S., Minneapolis, Minn.

BARTON, R. H.
E.I. duPont de Nemours & Co., Inc., 1750 Olden Ave., Trenton, N.J.

BATCHELOR, Harry H.
Special Representative, Society of Residential Appraisers, 14 W. Saratoga St., Baltimore 1, Md.

BEACH, Lewis S.
Mgr., Div. Bldgs. & Stores, Yale University, 20 Ashmun St., New Haven 11, Conn.

BEAUMONT, Ken
J.N. Steel Co., Ltd., Kernhouse, 36/38 Kingsway, London W.C. 2, England

BEAVERS, Wm. P.
Exec. Vice-Pres., The Biddle Co., 2817 Breckenridge Industrial Ct., St. Louis 17, Mo.

BECKER, John W.
Tech. Service Dir., Pecora, Inc., 300-400 W. Sedgley Ave., Philadelphia 40, Pa.

BEDDOW, C. A. Jr.
Architect, E.I. duPont de Nemours & Co., Inc., 13W18 Louviers Bldg., Engr. Dept., Wilmington 98, Del.

BEDICS, Michael
Chief Engineer, Pawling Rubber Corp., Pawling, N.Y.

BEEN, Jerome L.
Administrative Vice Pres., Rubber & Asbestos Corp., 225 Belleville Ave., Bloomfield, N.J.

BEERS, H. P.
Architectural Designer, W. W. Laird, 200 W. 9th St., Wilmington, Del.

BERRY, William C., Jr.
Research Chemist, Presstite Div., Martin-Marietta Corp., 3738 Chouteau St., St. Louis, Mo.

BEYER, Arthur
General Engineer, Veterans Administration, Research Div., Munitions Bldg., Washington 25, D.C.

BEYNON, John
Staff Associate, Educ. Facilities Laboratories, Inc., 477 Madison Ave., New York, N.Y.

BEYNON, Robert
Dir. of Research, Board of Education of Ohio, 4501 N. High St., Columbus, Ohio

BEZENAH, W. H.
Asst. Chief Engineer, The Dow Chemical Co., 3200 W. Nelson St., Midland, Mich.

BLAICH, Charles F.
Supervisor, Tech. Service, American Cyanamid Co., Rubber Chem. Dept., Bound Brook, N.J.

BLAIR, John O.
Architect, The Detroit Edison Co., 2000 - 2nd Ave., Detroit 26, Mich.

BOCKSTOCE, Clifton M.
Zone Mgr., Pittsburgh Plate Glass Co., 579 Fifth Ave., New York 17, N.Y.

BOERRIGTER, Glenn C.
Education Research & Program Specialist, Office of Education, Dept. of HEW, 400 Md. Ave., Washington, D.C.

BOGERT, Charles A.
Engineer, Western Electric Co., 222 Broadway, New York, N.Y.

BOLTON, Elmer G.
Planning Engineer, New England Tel. & Tel. Co., 185 Franklin St., Boston, Mass.

BONZON, Philip G.
Supervisor of Design & Development, Cupples Products Corp., 2650 S. Hanley Rd., St. Louis, Mo.

BOONE, Ralph W.
Construction Supervisor, The Dow Chemical Co., P. O. Box 488, Midland, Mich.

BOURKE, Arthur
Tech. Market Development, National Starch and Chemical Corp., 1700 West Front St., Plainfield, N.J.

BOWLES, Gladys K.
Analytical Statistician, U.S. Dept. of Agriculture, 3025 Ontario Rd. NW, Washington, D.C.

BOWSER, George H.
Research Chemist, Pittsburgh Plate Glass Co., Box 11472 Pittsburgh 38, Pa.

BOYD, Robert A.
Asst. Dir. of Research Administration, University of Michigan, Cooley Bldg., Ann Arbor, Mich.

BRANIN, Francis S.
Pres., ASCO Products Corp., Meadow Road, Nixon, N.J.

BRODER, Charles
Mechanical Engineer, The Port of New York Authority, 111 Eighth Ave., New York 11, N.Y.

BROTHERSON, Donald E.
Professor, University of Illinois, Urbana, Ill.

BROWNING, D. Dwight
General Mgr., Bldg. Materials Research, Armstrong Cork Co., Research & Development Center, Lancaster, Pa.

BURNETT, Thomas E.
Mechanical Engineer, N.I.H., Bethesda, Md.

BURROWS, Charles W.
Architectural Consultant, Libbey-Owens-Ford Glass Co., 610 Fisher Bldg., Detroit, Mich.

BURWELL, John T. Jr.
Dir. of Research, American Radiator & Standard Sanitary Corp., 40 West 40th St., New York 18, N.Y.

CALLENDER, John Hancock
Associate Professor, Pratt Institute, Brooklyn 5, N.Y.

CAMPBELL, Roy A.
Mgr., Technical Sales&Service, Intercoastal Paint Corp., 2320 Edgewater Ave., Baltimore 22, Md.

CARLSTON, E. F.
Research Assoc., California Research Corp. (Box 1627), 576 Standard Ave., Richmond, Calif.

CARNES, Joseph J.
Dir., American Cyanamid Co., 1937 W. Main St., Stamford, Conn.

CHATELAIN, Leon, Jr.
Partner, Chatelain Gauger & Nolan, 1632 K St. NW, Washington 6, D.C.

CHENEY, A. J.
Development Specialist, E. I. du Pont de Nemours & Co., Wilmington 98, Del.

CHOWN, F. Donald
Engr. The Upjohn Co., 7000 Portage Rd., Kalamazoo, Mich.

CLARKE, David H.
Aluminium Limited Sales, Inc., 111 West 50th St., New York 20, N.Y.

CLAXTON, Edmund
VicePres., ArmstrongCork Co., 1116 Wheatland, Lancaster, Pa.

CLENEAY, W. Allen
Staff Architect AIA, Monsanto Chemical Co., 800 N. Lindbergh, St. Louis 66, Mo.

COGHLAN, Thomas F.
Electrical Engineer, Public Buildings Service, GSA, 6803 5th St. NW, Washington, D.C.

COLLINS, George J.
Dir., National Inventory of School Facilities, U.S. Office of Education, 400 Maryland Ave. SW, Washington 25, D.C.

COLLYER, Norman S.
Pres., F. H. Sparks Co., Inc., 49 W. 45th St., N. Y., 36, N.Y.

COLSON, Frank J.
Chief Development Engineer, U.S. Steel Homes Division, 2549 Charlestown Rd., New Albany, Ind.

COLWELL, Robert E.
Mgr. Development, Monsanto Chemical Co.,800 N. Lindbergh, St. Louis 66, Mo.

CONNOR, Neil
Dir., Architectural Standards, FHA, 811 Vermont Ave. NW, Washington 7, D.C.

COON, Milton C., Jr.
4 Pickwick Lane, Hollin Hills, Alexandria, Va.

COUTRAS, Alexander
Market Analyst, American Cyanamid Co., Berdan Ave., Wayne, N.J.

COWAN, Henry J.
Professor & Head, Dept. of Architectural Science, Univ. of Sydney, Sydney, Australia.

COXE, Weld
Vincent G. King Assoc., 917 Corinthian Ave., Philadelphia, Pa.

CROMLEY, Ray
Staff Correspondent, Newspaper Enterprise Assn., 1013 - 13th St. NW, Washington, D.C.

CROSSETT, George H.
Tech. Representative, Pittsburgh Plate Glass Co., One Gateway Center, Pittsburgh, Pa.

CULIN, N. N.
Associate, Frederick G. Frost Jr. & Associates, 30 E. 42nd, New York 17, N.Y.

DANIELSON, Olav
Project Mgr., Union Carbide Corp., 270 Park Ave., New York 17, N.Y.

DANNER, John R.
Tech. Service Representative, Shawinigan Resins Corp., Monsanto Ave., Springfield, Mass.

DAVIDSON, Frank A.
Chief, Specifications Dept., Harrison & Abramovitz, 630 5th Ave., New York 20, N.Y.

DELATTRE, J. I.
Plant Engineer, American Bridge Div., U.S. Steel Corp., P. O. Box 1107, Harrisburg, Pa.

DELEVANTE, Owen L.
Project Mgr., Harrison & Abramovitz, Architects, 630 5th Ave., New York 20, N.Y.

DENIG, Robt. F.
Superintendent, Plant Design & Construction, Western Electric Co., 222 Broadway, New York, N.Y.

DERBYSHIRE, L. G.
Specialist, Bldg. Components, General Electric Co., Laminated Products Dept., Coshocton, Ohio

DEWAN, Thomas P.
Engineer, Design Research & Review, General Electric Co., 1 River Rd., Bldg. 36, Schenectady 5, N.Y.

DICKENS, H. Brian
Head, Housing Section, Div. of Bldg. Research, National Research Council, Montreal Rd. Labs, Ottawa, Ontario, Canada.

DI NORSCIA, G. A.
Senior Development Engineer, B. F. Goodrich Sponge Products, Howe Ave., Shelton, Conn.

DOMITZ, Edward
Laboratory Head, The Parr Paint and Color Co., 18312 Syracuse Ave., Cleveland 10, Ohio

DONOVAN, Daniel K.
Research Engineer, Larsen Products Corp., P. O. Drawer 5938, Bethesda 14, Md.

DORRANCE, George P.
Dir. of Tech. Services, Turner Construction Co., 150 E. 42nd St., New York 17, N.Y.

DRATZ, B. A.
Chemical Engineer, New Products, Kimberly-Clark Corp., 128 North Commercial St., Neenah, Wis.

DREISER, Harry
Editor, Bldg. Construction, 5 S. Wabash Ave., Chicago 3, Ill.

DUNN, L. M.
Mgr., Bldg. Products and Structures Development, Aluminum Co. of America, P. O. Box 1012, New Kensington, Pa.

DUPLER, John
Thiokol Chemical Corp., 780 N. Clinton Ave., Trenton 7, N.J.

EAGLETON, Sterling P.
Asst. to the Administrator, National Gallery of Art, 6th St. and Constitution Ave., Washington 25, D.C.

ECONOMIDES, Leander
Chief, Mechanical Div., Voorhees Walker Smith Smith & Haines, 101 Park Avenue, New York 17, N.Y.

EDWARDS, J. W.
Monsanto Chemical Co., 800 N. Lindbergh Blvd., St. Louis 66, Mo.

EHRENKRANTZ, Ezra D.
Asst. Professor & Asst. Research Architect, University of California, Berkeley 4, Calif.

ELLIOTT, Ralph
Washington Editor, Electric Light & Power Magazine, Washington, D.C.

ENGLISH, J. Morley
Vice Chairman, Research, Dept. of Engineering, University of California, Los Angeles 24, Calif.

EVANS, Ben H.
Coordinator of Architectural Research, Texas Engineering Experiment Station, College Station, Tex.

EVANS, John M.
Tech. Writer, Florida Architect, 315 S.E. 9th Ave., Ft. Lauderdale, Fla.

FEID, Jack T.
Project Mgr., Owens-Corning Fiberglas Corp., Cash Ave., Newark, Ohio

FINCHUM, R. N.
Specialist, School Plant Management, Dept. HEW, Office of Education, 400 Maryland Ave. SW, Washington 25, D.C.

FISCHER, Robert E.
Editor, Architectural Record (F. W. Dodge Corp.), 119 West 40th St., New York 18, N.Y.

FISH, D. E.
Dir. of Marketing, Thiokol Chemical Corp., 780 N. Clinton Ave., Trenton, N.J.

FISHER, W. S.
Specialist, Office Lighting, General Electric Co., Nela Park, Cleveland, Ohio

FITZGERALD, Wm. P.
Tech. Service Coordinator, Butyl Div., Enjay Chemical Co., 60 West 49th St., New York 20, N.Y.

FLYNN, J. E.
Sales Mgr., Pyles Industries Inc., 20855 Telegraph Rd., Southfield, Mich.

FOLLEY, Milo D.
Partner, Sargent Webster Crenshaw & Folley, 2112 Erie Blvd E., Syracuse 3, N.Y.

FORTH, Leo, Jr.
Project Mgr., The Sherwin Williams Co., 101 Prospect Ave., Cleveland 1, Ohio

FOSGATE, Charles M.
Mgr., Product Development, B. B. Chemical Co., 784 Memorial Drive, Cambridge, Mass.

FOXLEE, F. H.
Tech. Service Engineer, Union Carbide Plastics Co., 270 Park Ave., New York, N.Y.

FRANZ, C. J.
Research Consultant, Allied Chemical Corp., Morristown, N.J.

FRIEDERICH, Lewis W.
Treasurer, A. Friederich & Sons Co., General Contractors, 710 Lake Ave., Rochester, N.Y.

FRIEDMAN, Tom R.
Partner, Friedman, Alschuler & Sincere, 130 N. Franklin St., Chicago 6, Ill.

FROWNFELTER, C. R.
Tech. Representative, Product Development, Pittsburgh Plate Glass Co., One Gateway Center, Pittsburgh 22, Pa.

GALLANT, Bert
Estimating Mgr., Limbach Co., 851 Williams Ave., Columbus 12, Ohio

GASTON, J. E.
Tech. Consultant, Armstrong Cork Co., Research & Development Center, Lancaster, Pa.

GERE, Charles B.
Project Mgr., Sargent-Webster-Crenshaw & Folley, 2112 Erie Blvd. E., Syracuse 3, N.Y.

GERECHT, Ash
Editor, Housing Affair, 1319 F St. NW, Washington, D.C.

GERMAN, J. W.
Market Mgr., Commercial Construction, Pittsburgh Plate Glass Co., One Gateway Center, Pittsburgh 22, Pa.

GEYSER, Albert I.
Pres., E. K. Geyser Co., 915 McArdle Roadway, Pittsburgh 3, Pa.

GIBBONS, E. V.
Research Officer, Div. of Bldg. Research, National Research Council, Montreal Rd., Ottawa, Canada

GILL, Grayson
Pres., Grayson Gill Inc., 1913 San Jacinto St., Dallas 1, Tex.

GILLETTE, Samuel F.
Research Chemist, Naugatuck Chemical Div., U.S. Rubber Co., Elm St., Naugatuck, Conn.

GLASBERG, Oscar S.
Editor, Glass Digest, 15 E. 40th St., New York 16, N.Y.

GLAVIN, G. M.
Commercial Analyst, Canadian Industries Ltd., Development Dept., 630 Dorchester Blvd. W., Montreal, Quebec, Canada

GLICKMAN, M.
Test Engineer, American Bridge Div., U.S. Steel Corp., P. O. Box 1107, Harrisburg, Pa.

GLYNN, T. W.
Dir., Plate & Rolled Glass Development, American Saint Gobain Corp., Box 929, Kingsport, Tenn.

GOLAR, Paul
Research & Development Engineer, E. F. Hauserman Co., 6800 Grant Ave., Cleveland 5, Ohio

GORDON, P. B.
Vice Pres., Wolff & Munier, Inc., 50 W. 44th St., New York 36, N.Y.

GOSS, D. E.
Sales, Tremco Mfg. Co., 10701 Shaker Blvd., Cleveland 4, Ohio

GREEN, Alan C.
Asst. Professor, School of Architecture, Rensselaer Polytechnic Institute, 5463 Delmar Blvd., St. Louis, Mo.

GRENADIER, George
Pres., The Grenadier Corp., 1590 E. 233rd St., New York 66, N.Y.

GRIFFIN, C. W.
Assoc. Editor, Engineering News Record, 330 W. 42nd St., New York 36, N.Y.

GRIFFITH, J. W.
Professor, School of Engineering, Southern Methodist University, Dallas, Tex.

GRIMM, Clayford T.
Mgr., Architecture & Engineering Dept., Zonolite Co., 135 S. LaSalle St., Chicago, Ill.

GROVE, C. S., Jr.
Dir. of Engineering Research, Syracuse University, P. O. Box 145, University Station, Syracuse 10, N.Y.

GRUNDER, Paul E.
Sales, Dow Corning Corp., Midland, Mich.

GUTHRIE, Don M.
New Consumer Products Planning, B. F. Goodrich Co., 500 S. Main St., Akron, Ohio

GUY, Rolland B.
Construction Economist, Battelle Memorial Institute, 505 King Ave., Columbus, Ohio

GUYER, Walter R.
Esso Research & Engineering Co., P. O. Box 215, Linden, N.J.

GWYN, James D.
Asst. Dir. Research, Libbey-Owens-Ford Glass Co., 1701 E. Broadway, Toledo, Ohio

HAEGER, Leonard G.
8762 Preston Place, Chevy Chase 15, Md.

HAGERTY, Andrew T.
Chief Engineer, The Adams & Westlake Co., 1025 N. Michigan St., Elkhart, Ind.

HALL, Richard C.
Dir. of Assoc. Products Laboratory, The Sherwin-Williams Co., 601 Canal Rd., Cleveland, Ohio

HAMMITT, Andrew B.
Pres., H&B Enterprise Corp., 1150 Southard St., Trenton, N.J.

HANDLER, A. B.
Professor, University of Michigan, Ann Arbor, Mich.

HANELLIN, Norman C.
Chemist, Sonneborn Chemical & Refining Corp., Hancox Ave., Belleville, N.J.

HANFT, John D.
Senior Engineer, Turner Construction Co., 1500 Walnut St., Philadelphia, Pa.

HANLON, Mark
Editor, BLBS News, Better Light Better Sight Bureau, 750 Third Ave., New York 17, N.Y.

HANN, Gordon E.
Executive Vice Pres., Tremco Mfg. Co., 10701 Shaker Blvd., Cleveland 4, Ohio

HARDY, Howard C.
Owner, Howard C. Hardy & Assoc., 53 W. Jackson, R. 652, Chicago 4, Ill.

HARDY, James D.
Fellow & Dir., John B. Pierce Foundation Laboratory, New Haven, Conn.

HARLAN, Robert
Architectural Engineer, Masonite Corp., Powis Rd., St. Charles, Ill.

HARPER, Richard O.
Engineer, New England Tel. & Tel. Co., 185 Franklin St., Rm 1203, Boston, Mass.

HARRIMAN, Alonzo J.
Architect, 292 Court St., Auburn, Me.

HAUSCH, Walter R.
Mgr., Loxite Development, The Xylos Rubber Company, 1200 Firestone Parkway, Akron 17, Ohio

HAZELTINE, J. E., Jr.
Asst. Dir. of Research, Armstrong Cork Co., Research & Development Center, Lancaster, Pa.

HEAGLE, E. R.
Specialist, Product Planning, General Electric Co., Coshocton, Ohio

HEALEY, N.
Tech. Superintendent, Minnesota Mining & Mfg. of Canada Ltd., Oxford St., London, Ontario, Canada

HEIDER, Scott
Mechanical Engineer, FHA, Washington, D.C.

HENRY, Elvin F.
Civil Engineer, Architectural Standards Div., FHA, 811 Vermont Ave. NW, Washington, D.C.

HERITAGE, Clark C.
Consulting Engineer, P. O. Box 1273, Tacoma 1, Wash.

HERZOG, Philip C.
Mgr., Bldg. Products Research, Glidden Co., 12430 Elmwood Ave., Cleveland 11, Ohio

HIGGINS, John J.
Chemist, Enjay Chemical Co., P. O. Box 45, Linden, N.J.

HILBUSH, Edward O., Jr.
Pres., West Chester Chemical Co., P. O. Box 39, West Chester, Pa.

HILDEBRANDT, Fred J.
Vice Pres., Harley, Ellington, Cowin and Stirton Inc., 153 E. Elizabeth St., Detroit, Mich.

HILGART, Arthur A.
Chief Engineer, Bldg. Construction Engineers, The Upjohn Co., 301 Henrietta St., Kalamazoo, Mich.

HILLIER, James
Vice Pres., RCA Laboratories, RCA, Princeton, N.J.

HILLSTROM, Robt. S.
New Chemicals Products Management, Union Carbide Chemicals Co., 270 Park Ave., New York, N.Y.

HOCHMAN, Stanley
Managing Editor, Adhesives Age, 101 W. 31st St., New York 1, N.Y.

HOCKMAN, Arthur
Materials Engineer, National Bureau of Standards, Washington, D.C.

HOIBERG, Arnold J.
Tech. Dir., Flintkote Co., Whippany, N. J.

HOLTZ, Robert T.
Sr. Product Engineer, B. F. Goodrich Chemical Co., 3135 Euclid Ave., Cleveland 15, Ohio

HORGAN, William J., Jr.
Designer, Pittsburgh Plate Glass Co., 1 Gateway Center, Pittsburgh 22, Pa.

HOROWITZ, Harold
AIA, Registered Arch., 4102 Wexford Dr., Kensington, Md.

HOVLAND, Lyle W.
Engineer, Alcoa, 1501 Alcoa Bldg., Pittsburgh, Pa.

HOWE, Gaius W.
General Engineer, NIH-USPHS Bethesda 14, Md.

HUDDLE, C. F.
Head, Tech. Facilities & Services Dept., Research Lab., General Motors Corp., 12 Mile & Mound Rds., Warren, Mich.

HUDSPETH, Robert B.
Architectural Consultant, Libbey-Owens-Ford Glass Co., 99 Park Ave., New York, N.Y.

HUNT, T. W.
Portlant Cement Assn., 33 W. Grand Ave., Chicago 10, Ill.

HURSH, John R.
Chief Engineer, Metal Products Div., Armco Steel Corp., 1001 Grove St., Middletown, Ohio

IRISH, Ellwood
Chief Engineer, Unistrut Corp. 4118 South Wayne Road, Wayne, Mich.

JACKSON, Dale E.
Research Assoc., Butler Mfg. Co., 135th & Botts Rd., Grandview, Mo.

JANSSON, John P.
Architect, Sugar Tom's Ridge, East Norwich, L.I., N.Y.

JAROS, Alfred L., Jr.
Jaros, Baum & Bolles, 730 3rd Ave., New York 17, N.Y.

JENSEN, A. G.
Mgr., Architectural Relations, Pittsburgh Plate Glass Co., 1 Gateway Center, Pittsburgh 22, Pa.

JENSEN, Meredith
Baldwin-Ehret-Hill, 500 Breunig Ave., Trenton 2, N.J.

JOHNSON, Gardner O.
St. Clair Rubber Co., 1434 Land Title Bldg., Philadelphia 10, Pa.

JOHNSON, H. M.
Product Mgr., Union Carbide Corp., Silicones Div., 270 Park Ave., New York, N.Y.

JOHNSON, Herbert H.
Partner, Herbert H. Johnson Assoc., 550 Brickell Ave., Miami 32, Fla.

JOHNSON, P. I.
Development Engr., Diamond Alkali Co., Union Commerce Bldg., Cleveland, Ohio

JONES, Rudard A.
Director, SHC-BRC, University of Illinois, Urbana, Ill.

JORDAN, Richard C.
Prof. & Head, Dept. of Mech. Eng., University of Minnesota, Minneapolis 14, Minn.

KALVIN, E. G.
Bldg. Engineer, Procter & Gamble Co., Ivorydale Tech. Center, Cincinnati 17, Ohio

KAPLAN, Julius F.
Tech. Coordinator, Curtis Products, Inc., Div. of Helene Curtis Ind., Inc., 4401 W. North Ave., Chicago 39, Ill.

KATZ, Lawrence
Architectural Engr. (Specialist S Specs.) GSA, Public Bldgs. Service, 19th & F Sts., N.W. Washington 25, D. C.

KEANE, Gustave R.
Production Administrator, Eggers & Higgins, Architects, 100 E. 42nd St., New York 17, N.Y.

KEANE, John J.
E.I. du Pont de Nemours & Co., Film Dept., Chestnut Run Labs., Wilmington, Del.

KELLOGG, C. F.
Architect, The Upjohn Co. 301 Henrietta St., Kalamazoo, Mich.

KEMENDO, John J.
President, Naturalite, Inc., 5115 East Grand St., Dallas, Tex.

KEMMERLEY, J. R.
Sales Mgr., Thiokol Chemical Corp., 780 N. Clinton Ave., Trenton, N.J.

KETHMAN, Harold C.
Dir. of Research & Development, Gas Purifying Materials Co., Inc., 3-15 26th Ave., Long Island City, N.Y.

KEYES, Marcus W.
Fiber Glass Div., Pittsburgh Plate Glass Co., 1 Gateway Center, Pittsburgh 22, Pa.

KIME, Joseph M.
Tech. Supervisor, B. F. Goodrich Co., 500 S. Main St., Akron, Ohio

KING, Jonathan
Secretary & Treasurer, Educational Facilities Labs., 477 Madison Ave., New York 22, N.Y.

KIRKLAND, William G.
Asst. Vice Pres., American Iron & Steel Institute, 633 3rd Ave., New York, N.Y.

KLEIN, Miles M.
Vice Pres., Gas Purifying Materials Co., Inc., 3-15 26th Ave., Long Island City, N.Y.

KLEINER, Anne May
Arch. (General), PHA, Room 1002 Longfellow Bldg., Washington, D.C.

KLIMENT, Stephen
Editor, Architectural & Engineering News, 500 Bloomfield Ave., Montclair, N.J.

KLINE, Charles H.
Pres., Charles H. Kline & Co., Inc., 256 Wanaque Ave., Pompton Lakes, N.J.
KLING, Vincent G.
Vincent G. Kling Assoc., 917 Corinthian Ave., Philadelphia, Pa.
KOCHIS, August J.
Federal Services Rep., Minnesota Mining & Mfg. Co., 425 13th St., N.W., Washington, D.C.
KONSTANDT, Felix
Tech. Dir., National Testing Labs., 44 Trinity Place, New York 6, N.Y.
KOPPES, Wayne F.
Arch. Consultant, 154 So. Alward Ave., Basking Ridge, N.J.
KUENNING, William H.
Senior Development Engr., Portland Cement Assn., 5420 Old Orchard Rd., Skokie, Ill.
KULP, Russell N., Sr.
Mech. Engr., Dept. HEW, PHS, NIH, Bethesda, Md.
LAIRD, Walter J., Jr.
Group Mgr., E.I. duPont de Nemours & Co., Film Dept., Chestnut Run, Wilmington, Del.
LANGTON, W. M.
Tech. Dir., Permatex Co., Inc., 1720 Ave. Y, Brooklyn 35, N.Y.
LARSEN, Phyllis H.
Pres., Larsen Products Corp., P.O. Drawer 5938, Bethesda 14, Md.
LARSON, C. Theodore
Professor of Architecture, University of Michigan, Ann Arbor, Mich.
LASKO, Richard T.
Head, Construction Economist, Battelle Memorial Institute, 505 King Ave., Columbus, Ohio
LEDERER, W. C., Jr.
Bldg. Engineer, The Bell Telephone Co. of Pa., 1329 Chestnut St., Philadelphia 7, Pa.
LeFAVE, G. M.
Vice Pres., Coast Pro-Seal & Mfg. Co., 19,451 Susana Rd., Compton, Calif.
LEFFEL, P. C., Jr.
Sales Mgr., Specialized Products, Corning Glass Works, Corning, N.Y.
LEONARD, Ethan L.
Southeastern Mgr., The Caloric Corp., 912 Thayer Ave., Silver Spring, Md.
LEWIS, Graham M.
Service Mgr., Cafritz Co., 1625 Eye St., N.W., Washington, D.C.
LEWIS, John C.
Facilities Engineer, IBM, 590 Madison Ave., New York 22, N. Y.
LEWIS, John R.
Mgr., Plastics/Elastomers Div., Hercules Powder Co., Wilmington, Del.
LIEBERMAN, E. F.
Chemical Engineer, E.I. duPont de Nemours & Co., Wilmington, Del.
LIU, Benjamin Y. H.
Asst. Prof., Dept. of Mech. Engineering, University of Minnesota, Minneapolis 14, Minn.
LOCKWOOD, W.H.
Bell Telephone Labs., Mountain Ave., Murray Hill, N.J.
LODGE, Joseph W.
Asst. Dir. Research, Youngstown Sheet & Tube Co., Box 900, Youngstown, Ohio
LOEWENSTEIN, Edward
Loewenstein-Atkinson Architects, 1030 E. Wendover Ave., Greensboro, N.C.
LOGAN, Henry L.
Vice Pres. in Charge of Research, Holophane Co., Inc. 1120 Ave. of the Americas, New York 36, N. Y.

LONG, George J.
Dep. Supt., Dept. of Licenses & Inspections, Govt. of D.C., Washington, D. C.

LOUCKS, Earl W.
Product Mgr., Thiokol Chemical Corp., 780 N. Clinton Ave., Trenton 7, N.J.

LOWENSTEIN, Milton D.
Dir., Tech. Research Service Center, Assn. for Applied Solar Energy, P.O. Box 114, Arizona State University, Tempe, Ariz.

LUCK, Allan J.
Masonite Corp., Powis Rd., St. Charles, Ill.

LUND, Herbert F.
Bldgs. & Facilities Editor, Factory Magazine, 330 W. 42nd St., New York 36, N.Y.

LYONS, I.
Bldg. Engineer, The Bell Telephone Co. of Pa., 1329 Chestnut St., Philadelphia 7, Pa.

MABBOTT, J. W.
Tech. Mgr., Rigid Plastics, B. F. Goodrich Co., Marietta, Ohio

MacCURDY, David
Consultant, Owens-Corning Fiberglas Corp., 717 Fifth Ave. New York 22, N.Y.

MacDONALD, J. T.
Controller of Plant, North York Bd. of Educ., 15 Oakburne Cre., Willowdale, Ontario, Canada

MacDONALD, S. L.
Assoc. Professor of Architecture, Dept. of Architecture, University of Utah, Bldg. 442, Salt Lake City, Utah

MacDONALD, T. H.
Meteorologist, U. S. Weather Bureau, 24th & M St., N. W., Washington, D.C.

MacLEAN, William M.
Market Research, Naugatuck Chemicals, 550 Papineau Ave., Montreal, Quebec, Canada

MAGEE, John W.
Contract Engineer, The Port of New York Authority, 111 8th Ave., Rm. 1115, New York 11, N.Y.

MAIER, Leonhardt F.
General Engineer, J. George Stewart, Architect of the Capitol, U.S. Capitol, Washington, D.C.

MALOBICKY, R. L. Jr.
Pittsburgh Plate Glass Co., Works No. 17, Ferry St., Creighton, Pa.

MANERI, Remo R.
Proj. Mgr., New Prod. Dev. Dept., Dow Corning Corp., Midland, Mich.

MARKUS, T. A.
Pilkington Brothers Limited, St. Helens, England

MARQUARDT, James
Acct. Executive, G. M. Basford Co., 60 E. 42nd St., New York, N. Y.

MARSH, James H., III
Asst. Research Arch., Texas A & M College, College Station, Texas

MASLOW, Philip
Tech. Dir., A.C. Horn Co., Sun Chemical Corp., 631 Central Ave., Carlstadt, N.J.

MATTHEWS, A. L.
Architectural Consultant, Libbey-Owens-Ford Glass Co., 120 S. La Salle St., Chicago, Ill.

McBURNEY, Dorman
Development Mgr., Fabrics & Finishes Dept., E.I. duPont de Nemours & Co., Inc., Market St., Rm. D-7012, Wilmington 98, Del.

McCARTHY, J. P.
Asst. Mgr., Product Development, Koppers Co., Inc., 15 Plum St., Verona, Pa.

McCARTHY, W.J.
B.F. Goodrich Chem. Co., P.O. Box 122, Avon Lake, Ohio

McCLELLAN, James M.
Product Mgr., Wyandotte Chemicals Corp., Biddle Ave., Wyandotte, Mich.

McKEEVER, Virgil A.
Development Engineer, The William Bayley Co., 1200 Warder St., Springfield, Ohio

McKINLEY, Robert W.
Mgr., Tech. Services, Pittsburgh Plate Glass Co., 1 Gateway Center, Pittsburgh 22, Pa.

McLAUGHLIN, Everett R.
Assoc. Prof. of Engineering Research, Pa. State University, University Park, Pa.

McMASTER, William W.
Architect, NIH-USPHS, Bethesda, Md.

MEESKE, Paul
Mgr., Construction Materials, The Dow Chemical Co., Midland Co., Midland, Mich.

MENDIS, P.
Market Development, CIBA Products Co., Route 37, Toms River, New Jersey

MILLARD, Charles F.
Assoc., Whitman, Requardt & Assoc., 1304 St. Paul St., Baltimore 2, Md.

MILLER, Richard R.
Vice Pres. & Sales Mgr., Laminated Glass Corp., 9797 Irwin Ave., Detroit 13, Mich.

MILLER, Vernon F.
Engineer, Rohm & Haas Co., Bristol, Pa.

MITCHELL, Thomas F.
Marketing Research Analyst, Pittsburgh Plate Glass Co., Gateway One, Pittsburgh, Pa.

MONK, C. B., Jr.
Mgr. of Research, Structural Clay Products Research Foundation, Geneva, Ill.

MONTROSS, Charles F.
Senior Management Analyst, American Cyanamid, 30 Rockfeller Plaza, New York 20, N.Y.

MORAZAIN, J. F.
Marketing - Architectural, Aluminum Co. of Canada, Ltd., P.O. Box 6090, Montreal, Quebec, Canada

MOREKAS, Sam
Architectural Engineer, NIH, (Engr. Design Section, PEB) Bethesda 14, Md.

MORGENROTH, Dan E.
Owens - Corning Fiberglas Corp., Toledo, Ohio

MORROW, R. L.
Senior Assoc. Engineer, I.B.M. Kingston, N.Y.

MOSHER, Paul
Development Engineer, Kelgo Co., 75 Terminal Ave., Clark, N.J.

MUESSEL, Dan C.
Mgr., Architectrual Products Div., Kawneer Co., 1105 N. Front St., Niles, Mich.

NAYLOR, Henry A., Jr.
Partner, Whitman, Requardt & Assoc., 1304 St. Paul St., Baltimore 2, Md.

NELSON, Joseph B.
Architect, Carl M. Freeman, Inc., 1111 Fidler Lane, Silver Spring, Md.

NELSON, Otto L., Jr.
Vice Pres. in Charge of Housing, N.Y. Life Insurance Co., 51 Madison Ave., New York 10, N.Y.

NEWMAN, E. M.
Civil Engineer, Hq., U.S. Air Force, Washington, D. C.

NEWMAN, Joseph H.
General Mgr., Tishman Research Corp., 666 Fifth Ave., New York 19, N.Y.

NILSSON, Curt
Pres., Nya Murbruksfabrikens (New Adhesives Factory), Jungfurgatan 8, Stockholm 6, Sweden

NOBES, William Douglas
Mgr., Design Eng., Caldwell Mfg. Co., P.O. Box 444, Rochester 2, N.Y.

NOCKA, Carl
Market Development Engineer, Enjay Chemical Co., 1141 E. Jersey St., Elizabeth, N.J.

NORMAN, Howard F.
Eastern Regional Sales Mgr., Rubber & Asbestos, 225 Belleville Ave., Bloomfield, N.J.

NYGREN, Maie
Head, Dept. of Housing & Interior Design, Oklahoma State University, Stillwater, Okla.

OBARA, Z. J.
Tech. Dir., DAP, Inc., 160 Dayton Ave., Xenia, Ohio

ODEGAARD, John
Dir., Research & Development, Kingsberry Homes Corp., 5096 Peachtree Rd., Chamblee, Ga.

O'DONNELL, J. R.
Research Engineer, Johns Manville Corp., Research Center, Manville, N.J.

O'HARE, Alex
Vice Pres., Miracle Adhesives Corp., 250 Pettit Ave., Bellmore, N.Y.

O'KONSKI, T. S.
Staff Asst., Operations, Wheeling Steel Corp., 1134 - 1140 Market St., Wheeling, W. Va.

OLGAY, Victor
Research Associate Professor, Princeton University, School of Architecture, Princeton, N.J.

OLSON, George E.
Marketing Research, The Dow Chemical Co., Midland, Mich.

ORBESEN, G. W.
Tech. Consultant, Libbey-Owens-Ford Glass Co., 811 Madison Ave., Toledo, Ohio

PALFEY, A. J.
The Dow Chemical Co., Midland, Mich.

PANEK, Julian R.
Mgr., Tech. Services Dept., Thiokol Chemical Corp., 780 N. Clinton Ave., Trenton 7, N.J.

PANEPINTO, Alfred
Chief Architect, Sun Oil Co., 1616 Walnut St., Philadelphia 3, Pa.

PARKINSON, John S.
Dir. of General Research & New Business Development, Johns-Manville Products Corp. Research Center, Manville, N.J.

PARRISH, M. R.
Product Development Engr., Granco Steel Products Co., 6506 N. Broadway, St. Louis, Mo.

PARSONS, D. E.
9119 Manchester Rd., Apt. 212, Silver Spring, Md.

PEARSON, Arthur J.
Mgr., Product Development, Owens-Corning FiberglasCorp. Case Ave., Newark, Ohio

PENNINGTON, Clark W.
Asst. Prof., Dept. of Mech. Engineering, Univ. of Fla., 1736 NW 14th Ave., Gainesville, Fla.

PENNINGTON, R. P. G.
Architectural Designer, The Bd. of Education for the City of Toronto, 155 College St., Toronto, Ontario, Canada

PERKINS, Lin F.
Representative, Solite Corp., P.O. Box 2015, Arlington 2, Va.

PERRIN, Nicholas
Engineer IV (Civil), The Port of N.Y. Authority, 111 Eighth Ave., New York 11, N.Y.

PERSSON, S. E.
Vice Pres., Amelco, Stow, Ohio

PETERSON, Patrick
Partner, H. S. Peterson Co., 155 Labelle St., Highland Park, Mich.

PETRY, Robert K.
Dir. of Research & Development, Congoleum-Nairn Inc., 195 Belgrove Drive, Kearny, N.J.

PETTIBONE, John
International Nickel Co., 67 Wall St., New York 5, N.Y.

PETTIGREW, D. W.
Staff Rep., Committee of Stainless Steel Producers, American Iron & Steel Institute, 633 3rd Ave., New York 17, N.Y.

PHILLIPS, Howard E.
Superintendent, Special Studies, Western Electric Co., 222 Broadway, New York 38, N.Y.

PIERCE, David A.
Research Architect for the Board of Education of Ohio, 4501 N. High St., Columbus, Ohio

PIERSON, Orville L.
Tech. Services, Rohm & Haas Co., 222 W. Washington Sq., Philadelphia 5, Pa.

PILOT
Vincent G. Kling Associates, 917 Corinthian Ave., Philadelphia, Pa.

PINKNEY, Paul S.
Research Assoc., E.I. DuPont de Nemours & Co., Electrochemical Dept., Buffalo Ave., Niagara Falls, N.Y.

PITCHFORTH, Lehi L., Jr.
Chemist, The Dow Chemical Co., Midland, Mich.

PITMAN, Edwin P.
Engineer of Materials, The Port of N.Y. Authority, 111 8th Ave., Room 1110, New York 11, N.Y.

POST, Howard W.
University of Buffalo, 94 N. Ellicott St., Williamsville 21, N.Y.

POUPITCH, O. Jules
Exec. Tech. Consultant, Fastex Div., Ill. Tool Works, Inc., 195 Algonquin Rd., Des Plaines, Ill.

PRANE, Joseph W.
Tech. Dir., Pecora, Inc., 300-400 W. Sedgley Ave., Philadelphia 40, Pa.

PREGMON, Walter
Development Chemist, E. I. duPont de Nemours & Co., 3500 Grays Ferry Ave., Philadelphia, Pa.

PURSIFULL, Ross W.
Project Dir., Smith, Hinchman & Grylls Assoc., Inc., 3107 W. Grand Blvd., Detroit 2, Mich.

QUEER, Elmer R.
Dir., Engr., Experimental Sta., College of Eng. & Architecture, Pa. State University, University Park, Pa.

QUINN, John J.
Pennsalt Chemicals Corp., P.O. Box 4388, Philadelphia 18, Pa.

RABE, William H., Jr.
Product Development Engr., Ceco Steel Products Corp., 5601 W. 26th St., Chicago, Ill.

RAPP, George M.
Fellow, Head of Eng. Div., John B. Pierce Foundation, 290 Congress Ave., New Haven 11, Conn.

RASCH, Herman R.
Engineer, National Steel, 6016 Wabash Ave., Terre Haute, Ind.

RAUSCHER, M. J.
Arch. Relations, Pittsburgh Plate Glass, 3034 N. 16th St., Philadelphia, Pa.

REED, John J.
Market Development, Olin Mathieson Chemical Corp., 460 Park Ave., New York 22, N.Y.

REIFENRATH, Peter
Consultant, Laminated Glass Corp., 9797 Erwin Ave., Detroit 13, Mich.

REIHER, Emil F.
Supervisor, Sealants & Ctg. Lab., Minn. Mining & Mfg.; Adhesives-Coatings & Sealers Div., 444 McKnight Rd., St. Paul, Minn.

RHODES, Edward C.
Project Coordinator, Dewey & Almy Chemical Div., W. R. Grace & Co., 62 Whittemore Ave., Cambridge 40, Mass.

RICHARD, W. R.
Monsanto Chemical Co., 800 N. Lindbergh Blvd., St. Louis 66, Mo.

RIGG, Richard W.
Vice Pres., Merchandising, American-Saint Gobain Corp., P.O. Box 929, Kingsport, Tenn.

RINGLE, Henry L.
Research Engineer, National Steel Corp., Research and Development Dept., Weirton, W. Va.

RINKLER, Jakies W.
Group Mgr., E.I. duPont de Nemours & Co., Film Dept., Chestnut Run, Wilmington, Del.

ROBINSON, A.E.
Research Chemist, Hercules Powder Co., Wilmington, Del.

ROECKER, Robert F.
Section Head, Adhesives, Armstrong Cork Co., Lancaster, Pa.

ROEHM, Jack M.
Vice Pres., Research & Development, Kawneer Co., 1105 N. Front St., Niles, Mich.

ROMANICK, John F.
Group Leader, R. & D., Rubber & Asbestos Co., 225 Belleville Ave., Bloomfield, N.J.

RORICK, Joseph A.
Mgr., Facilities Operation & Maintenance, IBM Corp., 590 Madison Ave., New York 22, N.Y.

ROYER, Eugene C.
Civil Engr., USAF Academy, Colorado Springs, Colo.

SAINT-AMOUR, H. E.
Chemist, Bldg. Products Ltd., 240 St. Patrick St., LaSalle, Quebec, Canada

SALLIE, Stanley H.
Development Mgr., Bird & Son, Inc., East Walpole, Mass.

SALMON, F. Cuthbert
Head, School of Architecture, Okla. State University, Stillwater, Okla.

SANDERS, Chas. M.
Product Mgr., Minneapolis-Honeywell Reg. Co., 2753 4th Ave., South, Minneapolis 8, Minn.

SAVAGE, R.
Mgr., Adhesives Dept., Chemical Div., Goodyear Tire & Rubber Co., E. Archwood Ave., Akron, Ohio

SAVAGE, R. J.
Development Engr., Archer Daniels-Midland Co., Investors Bldg., Minneapolis, Minn.

SCHAU, Ernest G.
Executive Editor, Practical Builder, 5 S. Wabash Ave., Chicago 3, Ill.

SCHELLENBACH, Stanley T.
Chief Chemist, Mastics Div., Steelcote Mfg. Co., 3418 Gratiot St., St. Louis 3, Mo.

SCHILLER, Arthur M.
Group Leader, American Cyanamid Co., 1937 W. Main St., Stamford, Conn.

SCHLEY, Henry M.
Mgr., Bldg. Design, Equitable Life Assurance Society, 1285 Ave. of Americas, New York 19, N.Y.

SCHMITT, Stanley W.
Tech. Rep., E. I. duPont de Nemours & Co., 1007 Market St., Wilmington 3, Del.

SCHNELLER, Frank J.
Assoc. Editor, Civil Engineering Magazine, 345 E. 47th St., New York 17, N. Y.

SCHNELLER, Joseph W.
Group Leader, Structural Products, National Gypsum Co., 1650 Military Rd., Buffalo, N.Y.
SCHRECKENGAST, W.
Kaiser Aluminum International, 300 Lakeside Dr., Oakland, Calif.
SCHREIBER, C. L.
Mgr., Product Development, Corning Glass Works, Corning, N.Y.
SCHUBERT, R. C.
Navy Dept., Bureau Yards & Docks, Washington 25, D.C.
SCHULTE, G. J., Jr.
Marketing Supervisor, Minnesota Mining & Mfg. Co., 900 Bush Ave., St. Paul 1, Minn.
SCHUTZ, Raymond J.
Vice Pres., Research & Development, Sika Chemical Corp., 35 Gregory Ave., Passaic, N.J.
SCHWEIZER, F. O.
Mgr., New Products Planning, Armstrong Cork Co., Liberty St., Lancaster, Pa.
SCOFIELD, Francis
Tech. Dir., National Paint, Varnish & Lacquer Assn, Inc., 1500 Rhode Island Ave. NW, Washington 5, D.C.
SCOTT, James A.
Special Products Engineer, Raybestos-Manhattan, Inc., PO Box 1021, Bridgeport 2, Conn.
SEGAL, Jacques
Staff Architect, NASA Headquarters, Washington, D.C.
SELLERS, M. D.
Mgr., Sales Development, Plastic Materials of Construction, B. F. Goodrich Chemical Co., 3135 Euclid Ave., Cleveland 15, Ohio
SHERR, Allan E.
Group Leader, American Cyanamid Co., 1937 W. Main St., Stamford, Conn.
SIMPSON, James R.
Engineer, FHA, Washington, D.C.
SMALL, Augustus B.
Research Assoc., Esso Research and Engineering Co., Park & Linden Aves., Linden, N.J.
SMELTZER, Paul O.
Chief, Dept. of Licenses & Inspections, Government of D.C., Washington, D.C.
SMITH, Clarence
Chemist, Product Development, Silicone Products Dept., General Electric Co., Mechanicville Rd., Waterford, N.Y.
SMITH, Donald M.
Research Fellow, Dupont (Plastics Dept.), Experimental Station, Wilmington 98, Del.
SMITH, E. M.
Research Engineer, American Iron & Steel Institute, 150 E. 42nd St., New York, N.Y.
SMITH, James R.
Staff Engineer, BRAB, 2101 Constitution Ave., Washington 25, D.C.
SMITH, Roscoe D.
Researcher & Specification Writer, Office of Douglas Orr, Architect, 111 Whitney Ave., New Haven, Conn.
SMITH, Vince
Chemical Week, McGraw-Hill Publishing Co., Washington, D.C.
SNEDEKER, John P.
Project Leader, Dow Corning Corp., 3812 Sharon Rd., Midland, Mich.
SNELGROVE, James A.
Research Section Leader, Shawinigan Resins Corp., Monsanto Ave., Springfield, Mass.
SNYDER, Marvin K.
Head, Bldgs. Research, Butler Mfg. Co., 135th & Botts Rd., Grandview, Mo.

SOLVASON, K. R.
Assoc. Research Officer, National Research Council, Division of Bldg. Research, Montreal Rd., Ottawa, Ontario, Canada

SONK, Michael J. Jr.
Marketing Mgr., Unistrut Corp., 4118 S. Wayne Rd., Wayne, Mich.

SOULE, John E.
Senior Regional Engineer, American Institute of Steel Construction, Inc., 815-17th St. NW, Washington 6, D.C.

SPIES, H. R.
Professor, University of Illinois, Urbana, Ill.

SPRING, Bernard P.
Architect, AIA, 10 W. Fordham Rd., New York 68, N.Y.

SPURNEY, F. E.
District Mgr., Butler Mfg. Co., 613 Cafritz Bldg., Washington 6, D.C.

STAIKOS, James J.
Arthur D. Little, Inc., Acorn Park, Cambridge, Mass.

STANLY, Lynn
Chemist, Chemical Sealing Corp., 5401 Banks Ave., Kansas City 30, Mo.

STARMER, Philip H.
Assoc. Development Scientist, B. F. Goodrich Chemical Co., P. O. Box 122, Avon Lake, Ohio

STELTZ, Irvin J.
Tech. Dir., Benjamin Foster Co., Ambler, Pa.

STEPHENS, Frederick
Civil Engineer, NIH-USPHS, Bethesda 14, Md.

STETINA, Henry J.
Engineer, AISC, 1617 Pa. Blvd., Philadelphia 3, Pa.

STUART, J. H.
Mgr., Facilities & Equipment Engineering, Merck Sharp & Dohme, West Point, Pa.

SULLIVAN, Nestor J.
Designer Engineer, E. I. du Pont de Nemours & Co., Engineering Dept., 33W11 Louviers Bldg., Wilmington 99, Del.

SWAN, W. Stanley
Tech. Sales Mgr., Pilkington Brothers (Canada) Limited, 55 Eglinton Ave. E., Toronto 7, Ontario, Canada

TALBOTT, John
Wood Technologist, Washington State University, Div. of Industrial Research, Pullman, Wash.

TALLMAN, K. L.
Sales Mgr., Kelco Co., 75 Terminal Ave., Clark, N.J.

TARBET, G. W.
Research Liaison, Dunlop Research Centre, 870 Queen St. E., Toronto 8, Ontario, Canada

TENZER, A. I.
Tenzer Assoc. Inc., 117 Liberty St., New York, N.Y.

THOMAS, G. E.
Metals Research Laboratories, Olin Mathieson Chemical Corp., 275 Winchester Ave., New Haven, Conn.

THOMPSON, M. Stafford
Mgr., Market Production, American Cyanamid Co., Wallingford, Conn.

THOMPSON, Stewart
Hellmuth, Obata & Kassabaum, Inc., 315 N. Tenth St., St. Louis 1, Mo.

THOMPSON, Ted E.
Engineer, Bethlehem Steel Co., Research Dept., Bethlehem, Pa.

TIBBETTS, D. C.
Officer in Charge, Atlantic Regional Station, Div. of Bldg. Research, National Research Council, Montreal Rd. Labs., Ottawa, Ontario, Canada

TINNING, Herbert P.
Tech. Secretary, ASHRAE, 345 E. 47th St., New York, N.Y.

TODD, C. I.
Dist. Mgr., Arch. Relations, Pittsburgh Plate Glass Co., 579-5th Ave., New York, N.Y.

TONS, Egons
Asst. Professor of Materials, Dept. of Civil Engineering, M.I.T., Cambridge, Mass.

TRECHSEL, Heinz R.
Architect, U.S. Steel Corp., Research Laboratory, Monroeville, Pa.

TURNER, Richard M.
Market Development, E. I. du Pont de Nemours & Co., Inc., Elastomer Chemicals Dept., P. O. Box 406, Wilmington, Del.

TWISS, Sumner B.
Pres., Cycleweld Chemical Products Div., Chrysler Corp., 5437 W. Jefferson, Trenton, Mich.

UHLMAN, Bob
Engineering Mgr., Limbach Co., 851 Williams Ave., Columbus 12, Ohio

UHR, Saul
Structural Engineer, Public Housing Administration, Washington, D.C.

UTT, Wm. E.
Mech. Engineer, NIH-USPHS, Bethesda 14, Md.

VALENTIEN, Wm., Jr.
Architectural Representative, Minn. Mining & Mfg. Co., Bristol, Pa.

VALENTINE, James H.
Tech. Sales Representative-Sealants, Pittsburgh PlateGlass Co., Island and Preble Aves., Pittsburgh 33, Pa.

VECONI, Gilbert J.
Research Engineer, Cupples Products Corp., 2650 S. Hanley Rd., St. Louis 17, Mo.

VERHOEVEN, Fred
Asst. Editor, Chemical & Engineering News, 1155-16th St., Washington, D.C.

VERSCHOOR, J. D.
Market Specialist, Johns Manville Corp., Research Center, Manville, N.J.

VILD, Donald J.
Technical Engineer, Libbey-Owens-Ford Glass Co., 1701 E. Broadway, Toledo 5, Ohio

VON BLON, William R.
Research Engineer, Veterans Administration, Munitions Bldg., 21st St. & Constitution Ave., Washington 25, D.C.

VON OTTO, Robert E.
Chief, Air Conditioning & Refrigerating Section, GSA, PBS, GSA Central Office Bldg., Washington 25, D.C.

WAGGENER, Spalding
Bldg. Editor, House & Garden, 420 Lexington Ave., New York, N.Y.

WAKEFIELD, Harold F.
Consultant, H. F. Wakefield Co., 77 Beverly Rd., Upper Montclair, N.J.

WALTER, Andrew T.
Asst. Dir. of Research, Union Carbide Corp., S. Charleston, W. Va.

WALTER, Sylvester H.
Architectural Engineer, E. I. du Pont de Nemours & Co., Louviers Bldg., Wilmington 98, Del.

WALTON, William W.
Chief, Organic Bldg. Materials Section, NBS, Washington 25, D.C.

WANGEROW, Leroy
Head of Development Dept., Servicised Products Corp., 6051 W. 65th St., Chicago, Ill.

WATTERS, Bill G.
Acoustical Engineer, Bolt Beranek and Newman Inc., 50 Moulton St., Cambridge 38, Mass.

WEBSTER, Arthur G.
Engineer, E. I. duPont de Nemours & Co., Engineering Dept., Wilmington 98, Del.

WEINGARTEN, Steve
Secretary, Standard Waterproofing Corp., 207 E. 120th St., New York, N.Y.

WELLINGTON, F. C.
Mgr., Planning & Development, Monsanto Chemical Co., 800 N. Lindbergh Blvd., St. Louis 66, Mo.

WENZLER, Otto
Mgr., Tech. Service, Libbey-Owens-Ford Glass Co., 811 Madison Ave., Toledo, Ohio

WERKEMA, T. E.
Plastics Dept., Dow Chemical Co., Midland, Mich.

WHITE, Burton B.
Market Development, General Electric Co., Silicone Products Dept., Waterford, N.Y.

WIETING, Wesley S.
Research Dir., Perkins & Will, Architects-Engineers, 309 W. Jackson Blvd., Chicago 6, Ill.

WILLIAMS, George M.
Chief Development Engineer, U.S. Rubber Co., 1 Market St., Passaic, N.J.

WILLIAMS, W. L.
Sales Representative, Enjay Chemical Co., 60 W. 49th St., New York 20, N.Y.

WILLIAMSON, James A.
Architect, Formica Corp., Spring Grove Ave., Cincinnati, Ohio

WILSON, Bill R.
Project Engineer, Butler Mfg. Co., 7400 E. 13th St., Kansas City, Mo.

WINCH, R. E.
Project Analyst, Sun Oil Co., 1608 Walnut St., Philadelphia 3, Pa.

WINDMAN, Arnold L.
Assoc., Syska & Hennessy Inc., 144 E. 39th St., New York, N.Y.

WINFIELD, Armand G.
Plastics Consulting Engineer, De Bell & Richardson, Inc., Hazardville, Conn.

WINNEY, J. R.
Senior Product Engineer, B. F. Goodrich Co., 500 S. Main St., Akron 18, Ohio

WINSTEAD, M. Franklin
Mgr., Extruder Dept., Intercoastal Paint Corp., 2320 Edgewater Ave., Baltimore 22, Md.

WINTER, Robert L.
Asst. to Pres., Pittsburgh Corning Corp., #1 Gateway Center, Pittsburgh 22, Pa.

WITHEY, William
Market Specialist, Armco Steel Corp., 703 Curtis St., Middletown, Ohio

WITTENWYLER, C. V.
Group Leader, Construction Applications, Shell Chemical Co., Union, N.J.

WORMSER, E. S.
Vice Pres., Research & Products, The Gibson-Homans Co., 2366 Woodhill Rd., Cleveland 6, Ohio

WRIGHT, Henry
Assoc. Professor, School of Architecture, Columbia University, New York 27, N.Y.

WRIGHT, James R.
Chemist, National Bureau of Standards, Washington, D.C.

WYCKOFF, W. R.
Marketing Mgr., Fabricated Products Div., Townsend Co., Water St., West Newton, Pa.

YOUNG, H. R.
Product Mgr.-Adhesives, E. I. du Pont de Nemours & Co. Inc., 8017 Dupont Bldg., Wilmington, Del.

YUNDT, A. P.
Dir. of Research, Bird & Son, East Walpole, Mass.

ZAHRNDT, Harold J.
Development Mgr., National Starch & Chemical Corp., 1700 W. Front St., Plainfield, N.J.

ZAKIM, Jerry
Pres., Jay Zee Protective Coatings, Inc., 7 Church St., Paterson, N.J.

ZEA, Charles F.
Asst. Chief Engineer, The William Bayley Co., 1200 Warder St., Springfield, Ohio

ZETTEL, J. H.
Dir., Research & Development, Johns Manville Research Center, Manville, N.J.

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